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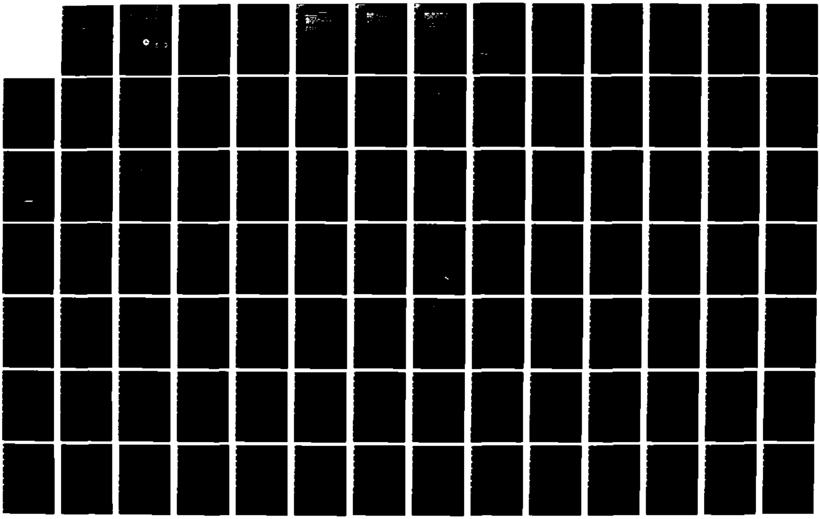

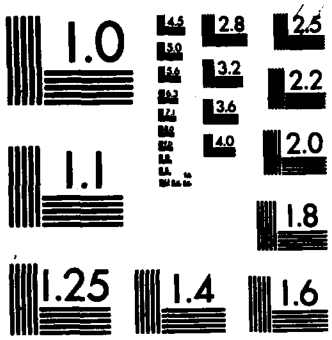

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Report No. FAA-EM-82-11

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POTENTIAL FUEL SAVINGS OF SPECIFIC ATC SYSTEM IMPROVEMENTS

Richard A. Rucker

The MITRE Corporation
McLean, Virginia 22102

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16. Abstract

Procedural restrictions are often imposed by the current ATC system upon the choice of routes and altitudes that the airspace user may fly. ATC-imposed delays before departure, while en route, or before landing are also a common experience. To the extent that such restrictions and delays impose fuel or time penalties, they are of concern to today's fuel/cost conscious airspace user. To the extent they are needed to resolve actual conflicts between aircraft competing for the use of common airspaces or runways, they are essential for maintaining air safety. However, to the extent that they simply "separate aircraft from otherwise empty airspace or runways", they impose unnecessary and costly penalties on the airspace users.

This report analyses the results of two recent FAA studies of these problems and also presents some previously unpublished case studies in attempt to better understand the causes and consequences of specific restrictions and delays to IFR flight movements. The report also estimates the potential for fuel savings if the ATC system could be improved to the point where only those restrictions and delays actually needed to insure flight safety are actually imposed. These potential fuel savings are allocated as the estimated benefits of five specific ATC system functional improvements now being considered by the FAA.

17. Key Words ATC Automation, Air Traffic Control, Fuel Conservation, Automated En Route ATC	18. Distribution Statement DISTRIBUTION STATEMENT A Approved for public release; Distribution Unlimited

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[illegible] (1) [illegible] by constantly imposing [illegible] restrictions, and (2) has difficulty [illegible] without [illegible] system [illegible] fuel penalties which, at today's prices, [illegible]

[illegible] route and altitude restrictions are most commonly [illegible] of the major terminal areas, below [illegible]. Beyond 150 miles or so and at or above FL310, [illegible] departures and arrivals can be expected to be level at [illegible], as well as spread out geographically, so that the difficulties ATC has in planning, coordinating, and controlling separations and spacings are greatly reduced.

[illegible] delays are known to occur due to ATC-imposed flow restrictions, even during periods when runways are under-utilized. The extreme sensitivity of expected delays to even small losses in runway throughput during periods of saturating demand has been demonstrated by computer simulation and confirmed by analysis of actual IFR operations. Observed losses in IFR runway throughput reflect the current difficulties the system has in planning and coordinating flight movements well in advance of the time of actual runway use.

Conclusions Reached About the Problem

Based on several case studies taken from the Washington center area, a review of the data and results of the operational evaluation referred to as "Operation Free Flight", and a review of the results of the "Northeast Area Procedural Study", the following conclusions seem justified (see section identified for details):

Regarding Routine Route and Altitude Restrictions

1. Flying airways versus flying the most fuel efficient random routes may impose a 2% fuel penalty on the average, nationally. (Section 4.1)

2. Within 150 miles or so of the major terminal areas, ATC-imposed restrictions can cause significant fuel penalties, relative to the routes and altitudes that would otherwise

[illegible] of up to 77%, and [illegible] the actual trip fuel burn of [illegible] found [illegible] review of each [illegible] concluded that most are still [illegible] and the demands placed [illegible]

3. [illegible] on actual traffic movements [illegible] frequency of potential conflicts is low enough [illegible] clearing of the desired routes and altitudes feasible, in lieu of rigidly imposed flow segregation rules. (Sections 3.2.2, 3.3, and Table G.5)

4. The potential for fuel savings by reducing the need for routine route/altitude restrictions is roughly estimated at 3% of the national annual consumption of jet fuel in civil aviation, or about 300 million gallons annually. (Section 5.1.2)

Regarding Excessive Delays for Arrivals

1. With a saturating demand, a 6% loss in runway throughput (33 aircraft landed versus a capacity to land 35) leads to a 200% increase in expected delay per aircraft (150 seconds versus 50 seconds). (Section 2.3.1)

2. Comparison of actual delays at Atlanta with an analysis of needed delays for the same traffic revealed that, for the observation period, 3 out of every 4 minutes of actual delay was potentially unnecessary. (Section 5.1)

3. The potential for fuel savings from reducing the need for excessive delays is roughly estimated at 300 million gallons annually, or about 3% of the national annual fuel consumption in civil aviation. This is in addition to the 3% savings cited above, and it is also in addition to any savings achieved by current attempts at automating profile descent and en route metering procedures (Section 5.1.1).

Regarding the ATC Improvements Needed

1. The potential savings above are calibrated against the expected performance of an improved ATC system with more sophisticated flow and clearance planning and control processes. The assumption is made that the system would apply only those restrictions and assignments necessary for safety between actual aircraft movements. Further, that when an ATC restriction or assignment is needed, it does not protect an unnecessarily large airspace volume for an unnecessarily long

[illegible] to be [illegible] concepts [illegible] do, however, demand a [illegible] the capabilities of [illegible] Model 3 and [illegible]

[illegible] through the elimination of [illegible] altitude restrictions, the [illegible] capabilities will be needed:

a. [illegible] to dynamically model the consequences [illegible] altitude profiles, and speed [illegible], taking into account the effects of expected [illegible] temperatures aloft, severe weather to be avoided, [illegible] capacity limits.

b. [illegible] dynamically compute the airspace that needs to be [illegible] expected flight paths are predicted to [illegible] in space and time, taking into account not only the appropriate separation standard, but also the error statistics of measured or predicted values and of expected individual flight variability about assumed norms.

c. In the event of a predicted shared airspace use problem, to dynamically compute or otherwise plan the least penalizing solution to that problem, and to dynamically coordinate that solution, if necessary, with any other ATC entity that might be affected.

d. To issue that solution in a timely way to the flight(s) involved for pilot acceptance, and for subsequent execution.

e. To subsequently monitor served flight movements for unacceptable deviations from previously issued clearances, and to revise those clearances or to correct those deviations as needed. To also monitor the 3-space (x, y, z) track positions and velocities of all served aircraft relative to each other, and to other known traffic, and to intervene if ever a loss of separation appears imminent.

3. To achieve the additional 3% fuel savings through the elimination of unnecessarily conservative flow and metering restrictions, an improved en route metering system, coupled with flexible profile descent procedures, will be needed which can:

a. Ensure that aircraft are fed to the final sequencing areas closely matched to dynamically computed runway capacities.

b. Make use of along-course speed reductions in cruise and descent whenever landing delays are known to exist, after discounting for known prediction error statistics.

c. Use vectoring and holding procedures only when necessary (i.e., when the currently discounted delays are greater than speed reductions alone can absorb),

d. Assume that large, predictable delays will be absorbed before departure by system planning and dispatch coordination at the national level.

4. A staged sequence of five steps to achieve the above functional improvements is postulated in Section 5 (Table 5.1). As postulated, the majority of the benefits attributed to fuel savings are potentially achievable in the earlier stages (Table 5-2). The remaining fuel benefits and the majority of the controller productivity benefits are achieved in the later stages.

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1. INTRODUCTION

It is a common observation by pilots and others that the present ATC system too often "separates aircraft from empty airspace", rather than from other aircraft. Another way this is sometimes stated is that "runways and ATC system capacities often saturate with aircraft, but airspace rarely, if ever, does". Both observations point to the fact that the present ATC system imposes quite a number of route and/or altitude restrictions on a procedural (i.e., routine) basis. Such restrictions are usually traceable to limitations in the clearance planning, coordination, and control processes as they have evolved over the years. They are rarely, if ever, traceable to an excessive number of aircraft competing for the same airspace, based on real-time separation requirements alone.

Another observation is that the present ATC system has some difficulty in adjusting traffic flows to variable runway capacities without imposing excessive delays before the aircraft reach the destination terminal area. That is, after-the-fact analysis of actual runway utilization has shown the active runways to be under-utilized during periods when the ATC system was imposing landing delays on flights arriving that airport. These excessive delays are usually traceable to arrival flow planning, coordination, and control limitations of the present system design.

The main problem with both (1) routinely imposed route/altitude restrictions and (2) excessive landing delays is that they impose time and fuel burn penalties which, at today's prices, are quite costly to the airspace users.

The purpose of this report is to (1) document the existence and causes of such penalties in the current ATC system by numerous examples, and to (2) estimate the potential savings that might accrue from implementing certain functional improvements to that system. The potential savings are estimated only in terms of the extra fuel that would otherwise be burned, even though time savings would also be achieved in many cases. The improvements considered are currently being discussed by the FAA as part of the en route and terminal computer replacement program.

This work focuses on the impact of ATC-imposed procedural restrictions upon civil turbojet operations in airspaces within the Conterminous U.S. Such restrictions also exist for military flights, oceanic flights, and flights at low altitudes over the U.S., but analysis of the impact on the latter operations are beyond the scope of this study.

Most of this work was completed prior to the start of the controller's strike on 3 August 1981, so this work does not reflect any changes brought about as a result of operating the ATC system around a smaller controller staff. However, during the time this report was prepared for publication, the author tried to find, but did not discover, any changes which would invalidate the conclusions of this study.

This work was sponsored and directed by DOT/FAA's Office of Systems Engineering Management during FY81.

1.1 Where Procedural Route/Altitude Restrictions are Found

All ATC facilities coordinate and establish procedures for the handling of IFR flights entering, traversing, and leaving their airspaces. Some locations and altitudes are more impacted than others for a variety of reasons, so it is not uncommon to hear otherwise knowledgeable people argue the degree to which the current ATC system impacts fuel-conservative flight operations. For every claim that "I'm always routed around Joneses barn to get where I am going", someone else can present a contrary view: "Well, I always get a direct route when I ask for it".

A pretty good rule-of-thumb for where procedurally-imposed route and altitude restrictions can be found is: within 150 miles or so of major terminal areas and below Flight Level (FL) 310. Here is where turbojets are transitioning vertically between airports and their en route cruise altitudes, and where aircraft merge, separate, or cross over/under one another in the process of transitioning to the active runway, or to their en route courselines.

Beyond 150 miles or so, most turbojet departures and arrivals can be expected to be level at their cruise altitudes, as well as spread out geographically, so the difficulties ATC has in planning, coordinating, and controlling separations are greatly reduced. Also, level flights overflying such areas at altitudes higher than FL310 are unaffected by the flow restrictions imposed on arriving or departing traffic below them. Consequently, outside or above these areas, random direct routings can often be granted by ATC.

1.2 Where Excessive Landing Delays are Found

All ATC facilities which serve the major airports are faced with matching arrival rates to available runway and control capacities, whenever the demand for service approaches or exceeds those capacities. Larger delays are to be expected and are unavoidable when demand exceeds capacity for any significant time period. But significant delays are also known to occur due to ATC-imposed flow restrictions, even during periods when runways are under-utilized. This problem is not well documented because of difficulties in gathering the data and in making a proper analysis. However, it has been shown that significant excessive delays can be produced by small, potentially unnecessary, losses in runway throughput. They can be the result of informational time lags, arrival time and capacity prediction errors, and other coordination and control problems that exist within and between those ATC facilities involved (approach control facilities, en route centers, the central flow control facility).

Given the rudimentary tools of today's ATC system for matching traffic demand to expected airport/airspace capacities, one can understand why the landing delays taken prior to arrival at any major airport today are frequently excessive or unnecessary, based on essential capacity limits and aircraft separation standards alone. Though some buffering to account for the uncertainties inherent in resolving competition for the use of the active runway(s) will always be necessary, it is clear that the delays imposed by today's system could be made smaller and less frequent with an improved system.

2. SENSITIVITIES INVOLVED IN AVIATION FUEL CONSERVATION

This section first shows why the operators of aircraft are extremely sensitive to maximizing fuel efficiencies at today's prices. It then addresses some of the reasons why many of these operators have been pressuring the FAA to better accommodate fuel-efficient flight planning and operations in the air traffic control (ATC) system.

2.1 Sensitivity of Flight Operating Costs to Fuel Efficiency

Table 2-1 shows the actual fuel consumption for the years 1975 thru 1980, and the forecast fuel consumption for the years 1981 thru 1992, for civil aviation in the United States.* The forecast for 1981 shows that:

a. Air Carriers account for about 87% of the annual fuel burn, and nearly all of that is jet fuel.

b. General Aviation accounts for the remaining 13%, and that burn is split as 2/3 jet fuel and 1/3 aviation gasoline.

Figure 2-1 shows that fuel costs dominate direct operating costs from the standpoint of the typical air carrier. For every dollar of revenues, about 50¢ goes to the direct operating costs (DOC) of typical air carrier aircraft. Of that 50¢, the dominant expense is fuel & oil (30¢). Note that every penny that can be saved out of DOC can have significant leverage on the profit margin of the operator. Using the case illustrated in the figure, a 3% fuel saving adds 1% to the 3% profit margin for the operator, which represents a 33% boost to profits.

Clearly, anything which can be done within the ATC system to increase fuel efficiency without sacrificing safety, even if it is by small amounts, is in the best interest of the airspace users, civil or military.

2.2 Sensitivity of Fuel Efficiency to the Routes, Altitudes and Speeds Flown

Table 2-2 defines the three most commonly used speed schedules for level flight in turbojet aircraft. Figure 2-2 illustrates the fact that the Long Range Cruise (LRC) speed schedule is the one that minimizes the fuel burn in terms of gallons per nautical mile. It also shows that the minimum fuel burn

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* Similiar data on military aviation is not readily available.

TABLE 2-1

ESTIMATED FUEL CONSUMED BY UNITED STATES DOMESTIC CIVIL AVIATION

(millions of gallons)

Fiscal Year	Total Jet Fuel and Aviation Gasoline	Jet Fuel			Aviation Gasoline		
		Total	Air Carrier	General Aviation	Total	Air Carrier	General Aviation
Historical							
1975	8,825	8,393	7,860	533	432	20	412
1976	8,855	8,403	7,822	581	452	20	432
1977	9,563	9,088	8,385	703	475	19	456
1978	9,919	9,426	8,669	757	493	17	476
1979	10,632	10,107	9,275	832	525	15	510
1980	11,814	11,279	10,370	909	535	13	522
Forecast							
1981	12,074	11,492	10,512	980	582	11	571
1982	12,410	11,806	10,707	1,099	604	9	595
1983	12,695	12,076	10,902	1,174	619	7	612
1984	12,986	12,349	11,097	1,252	637	6	631
1985	13,266	12,607	11,292	1,315	659	5	654
1986	13,554	12,878	11,488	1,390	676	5	671
1987	13,878	13,180	11,683	1,497	698	4	694
1988	14,167	13,450	11,878	1,572	717	3	714
1989	14,441	13,708	12,073	1,635	733	2	731
1990	14,736	13,978	12,268	1,710	758	2	756
1991	15,011	14,236	12,463	1,773	775	2	773
1992	15,301	14,509	12,658	1,851	792	2	790

Source: Reference 7.

Fuel Costs Dominate Direct Operating Costs:

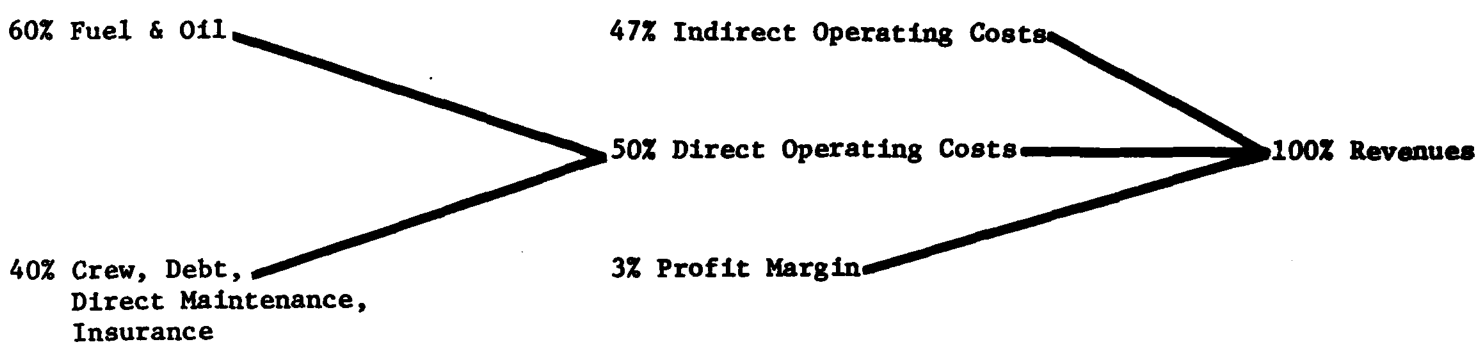

FIGURE 2-1
REDUCING OPERATING COSTS FOR AIRSPACE USERS

TABLE 2-2

BASIC SPEED SCHEDULES FOR TURBOJET AIRCRAFT

1. Long Range Cruise (LRC) Speed is that operationally useful speed which minimizes fuel consumption in terms of pounds (or gallons) of fuel burned per mile.*

   Implication: Use this speed schedule when delays are not expected.

2. Maximum Endurance Speed (MES) is that operationally useful speed which minimizes fuel consumption in terms of pounds (or gallons) of fuel burned per minute.

   Implication: Use this speed schedule when being held to absorb landing delays.

3. Constant Mach: For example: . 76, .78, .80, .82, .84 Mach

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* Note that this is a more generic definition of LRC speed than others currently used; e.g., that speed which is 1% higher than the speed at which specific range is maximized.

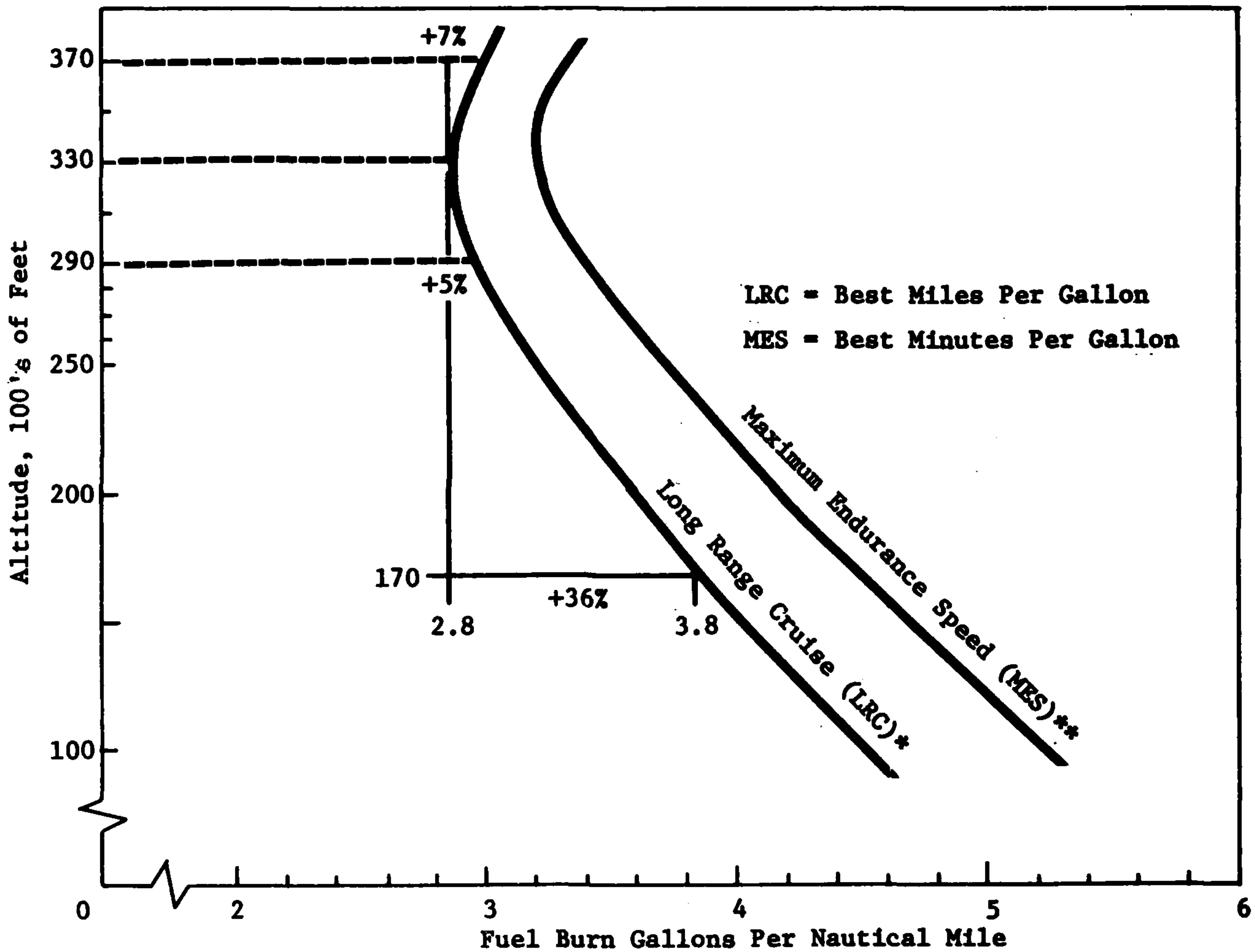

FIGURE 2-2
FUEL BURN VS. ALTITUDE FOR A B727-225A 160 KLBS, STANDARD DAY

achievable at LRC, in terms of gallons per mile, is quite sensitive to the altitude flown. In this example, a medium weight B727-225A on a standard temperature day will clearly do its best at, and only at, Flight Level 330.

It should be clear from Figure 2-2 that:

1. A non-direct route to a flight's destination, because it adds extra flying miles, imposes a fuel penalty on every user constrained to fly one. For a medium-weight B727-225A flying at its optimal altitude, the fuel penalty is about 3 gallons for every extra mile flown.

2. An altitude restriction which causes an aircraft to fly at other than its optimal altitude also imposes a fuel penalty. For a medium-weight B727-225A whose optimum cruise altitude is FL330, flying at the next same-way flight level above or below FL330 extracts a significant penalty:

Eastbound Altitude (100's of Feet)	Fuel Penalty (as Percent of Gals./Mile)
370	+ 7%
330	+ 0%
290	+ 5%
170	+ 36%

As is explained in subsequent sections, one of the biggest complaints airspace users have regarding the ATC system today is the frequent procedural use of non-direct routes and altitude restrictions. To the extent that such restrictions are imposed in situations where actual traffic conditions fail to justify them, the users can rightly claim that the ATC system is unnecessarily penalizing them in an area where it hurts.

Except for the regulatory speed limit of 250 knots below 10,000 feet and in certain in-trail and delay-absorbing situations, airspace users generally are unrestricted by the ATC system as to what speeds can be flown. Consequently, ATC-imposed speed restrictions have not been a problem in the same way that route or altitude restrictions have been. At today's fuel prices, most carriers have instructed their pilots to operate fairly close to LRC speed in level flight.

2.3 Sensitivity of Fuel Efficiency to Runway Utilization Efficiency and Delay Absorption Techniques

When demand for the use of a runway exceeds its capacity, some landing delays are inevitable. Because any landing delay must be absorbed before the aircraft can be spaced with other aircraft in the final approach sequence, a process is required which translates the mis-match between runway demand and runway capacity into explicit delay-absorbing maneuvers. These maneuvers must be executed before the aircraft reaches the final sequencing and spacing area.

In principle, that process for arriving turbojet aircraft involves:

1. An estimate by the approach control facility as to the expected acceptance rate for the next hour, i.e., so many landing slots per hour per independent runway, or

   A computed tentative landing schedule based on the flight plans of known arrivals to the runway. Such a schedule can be thought of as a dynamically computed acceptance rate which takes into account actual traffic demand, including the mix of aircraft types and their likely landing sequence.*

2. A method of allocating those slots (or tentative landing times) to the several terminal area feeder fixes for turbojet traffic, setting aside sufficient slots for prop and other local traffic.

3. The use of spacing criteria (in time or distance) and delay-absorbing maneuvers to insure that the resultant flow rates (or "no earlier than" time schedules) established for each feeder fix are not exceeded.

Such a metering process, since it is largely executed by the en route center which feeds the terminal area, is referred to as "en route metering". Depending upon the details of the particular implementation, the performance of such a process as judged from a fuel-efficiency standpoint can vary quite widely. See Reference 1 for a theoretical analysis of such performance, and see Reference 5 for an analysis of delays actually observed being taken by arrivals to the Atlanta Hartsfield airport.

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* This latter method is far less susceptable to mis-matching runway utilization with runway capacity.

2.3.1 Fuel Efficiency vs Runway Utilization Efficiency

When a saturating demand for the runway exists, it is very important for fuel efficiency to keep actual runway utilization running close to maximum runway capacity. Figure 2-3 illustrates why.

Assume that a runway has a maximum arrival capacity of 35 aircraft per hour. Furthermore, assume that the arriving aircraft are being metered according to a tentative landing schedule so that they cross the terminal area feeder fixes with an unbiased delivery error of 1 minute (one standard deviation). Figure 2-3 shows what happens to the expected (average) delay per arrival if the actual throughput is only 33 arrivals per hour, when the actual runway capacity is 35 per hour. With a saturating demand of 35 aircraft per hour and with the amount of de-randomizing already done by the en route metering process, each arrival can still expect something short of 1 minute's delay on the average, when actual utilization matches capacity.* But let that utilization fall by only 2 slots per hour (a 6% reduction in landing rate) and the expected delay jumps non-linearly to about 2.5 minutes for each aircraft (a 150% increase in delay).

Such a reduction in runway utilization can occur for any number of reasons including (1) a slight underestimate of how many aircraft can actually land during the next hour, and (2) differences in the delay needed versus the delay actually taken by each aircraft in the landing sequence.

To an observer watching the active runway, a 6% reduction in the landing rate is probably imperceptible. To a fuel-conscious pilot of say a B727-class aircraft, it means that an extra 35 gallons or so of fuel was burned.

Figure 2-4 illustrates the sensitivity of the expected delay per aircraft as a function of demand for various levels of mis-match between actual throughput and available capacity.

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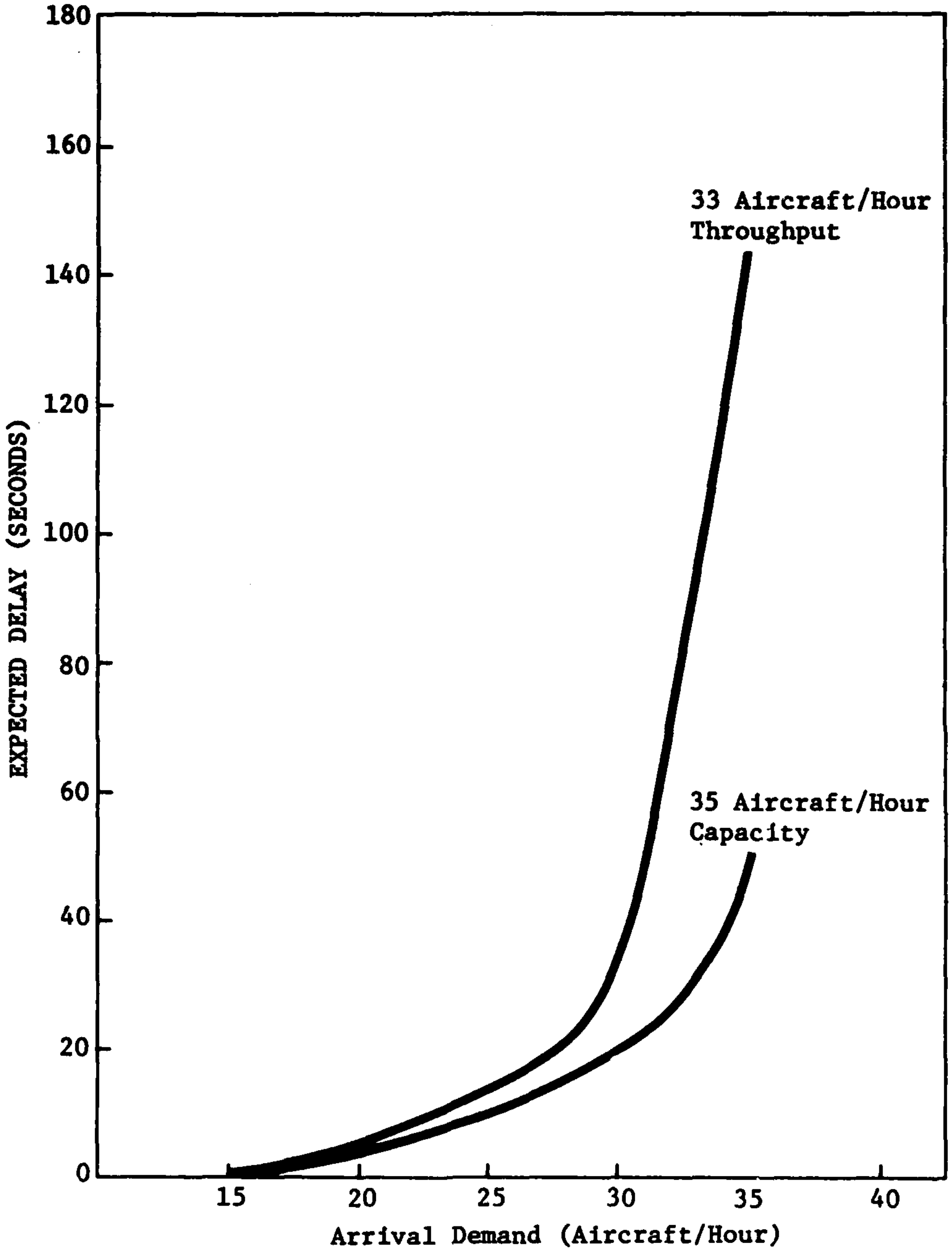
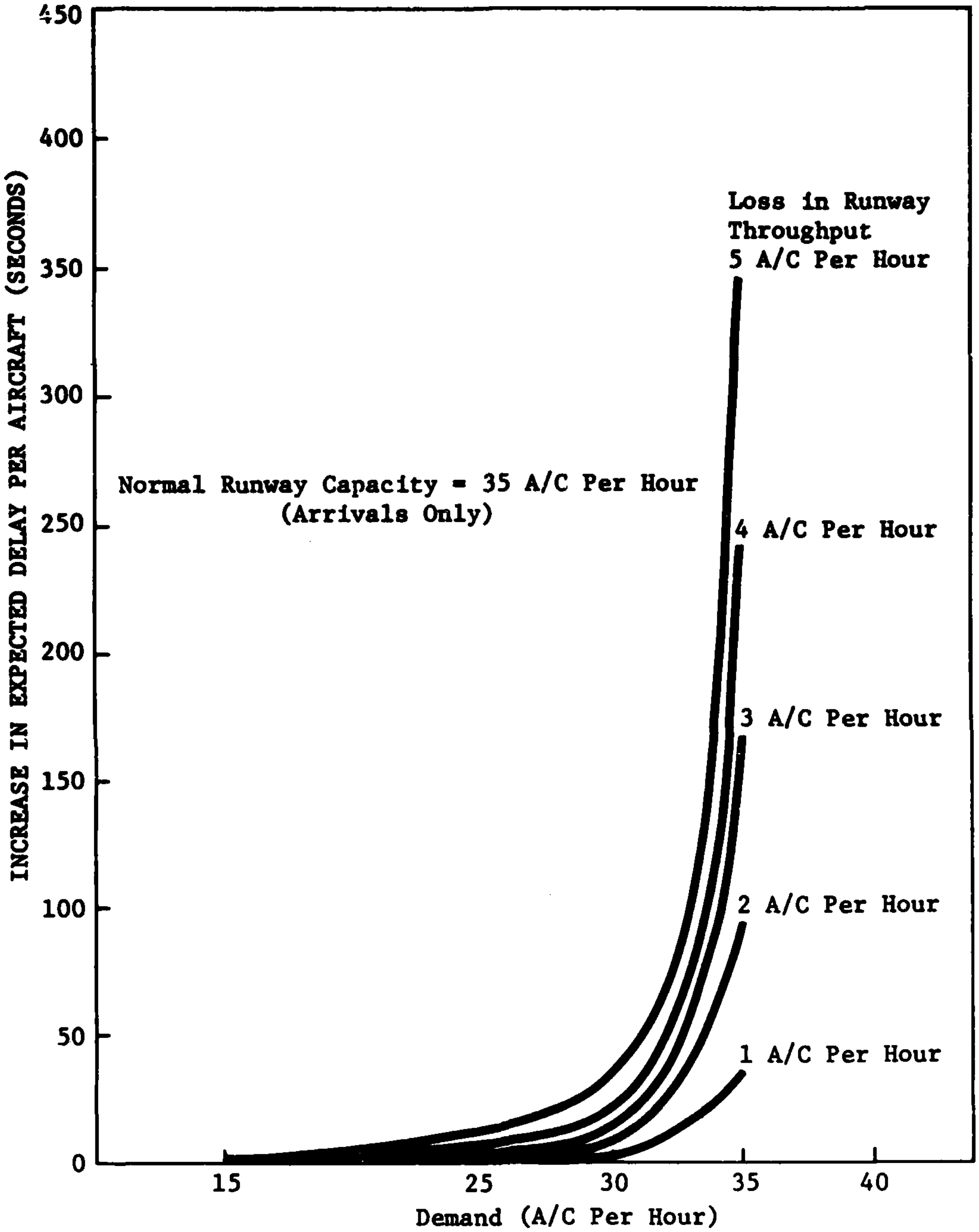
* The metering process does not perfectly de-randomize the arrival flow, so some small delays are incurred in order to achieve a properly spaced sequence for final approach.



Source: Reference 1

FIGURE 2-3
EXPECTED LANDING DELAYS AS A FUNCTION OF ARRIVAL DEMAND



Source: Reference 1

FIGURE 2-4
INCREASE IN LANDING DELAY DUE TO LOSS IN RUNWAY THROUGHPUT

2.3.2 Fuel Efficiency vs Delay Absorption Techniques

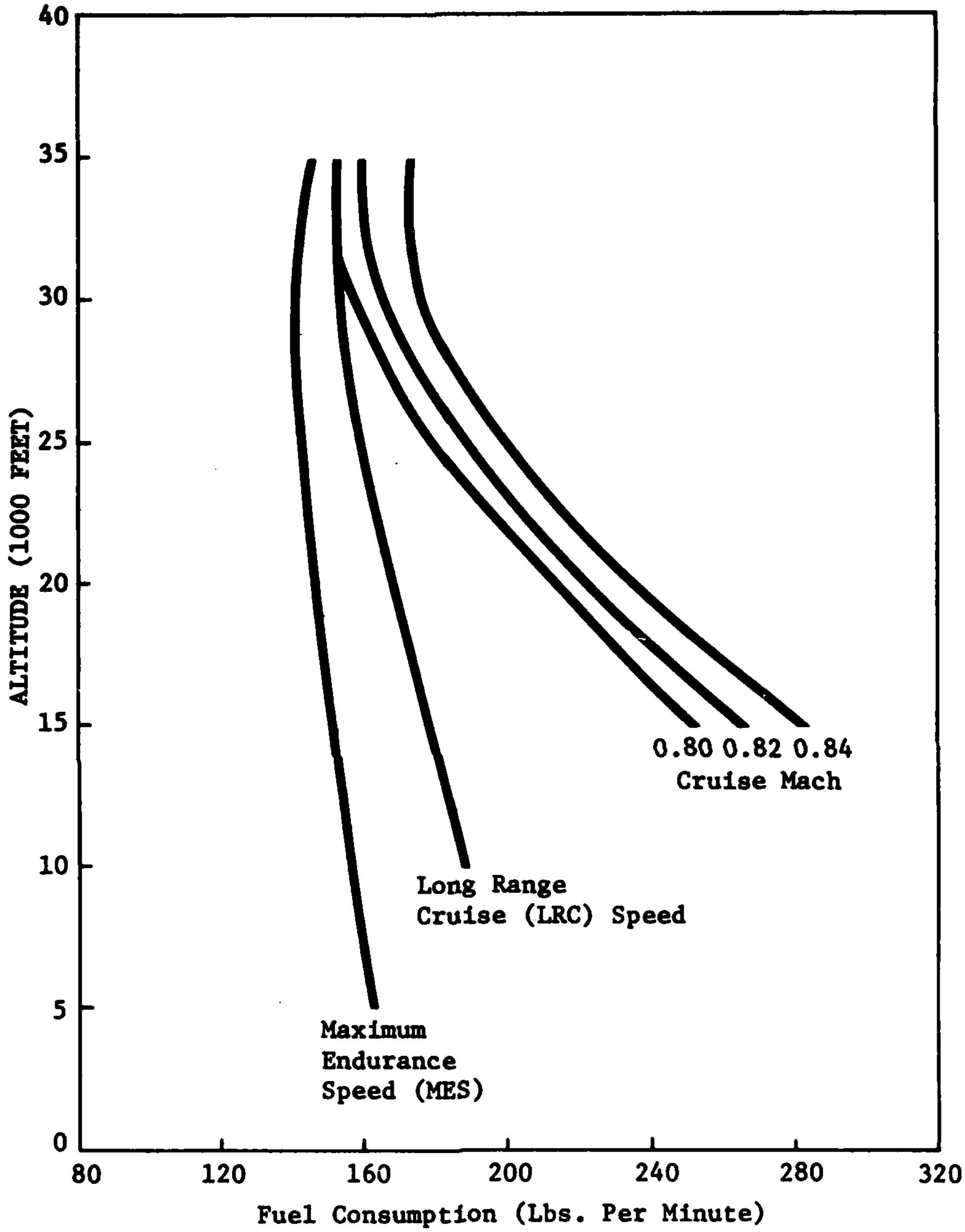
Figure 2-5 illustrates the fact that the Maximum Endurance Speed (MES) schedule is the one which minimizes the fuel burned in terms of pounds (or gallons) per minute of delay. It also shows that the minimum fuel burn achievable is somewhat sensitive to altitude, but not nearly so much as the LRC or constant mach schedules.

This point regarding the MES schedule is made more clearly using Figure 2-6. For a medium-weight B727-225A, the best altitude to take a delay at on a standard temperature day is about 31,000 feet. However, any delay actually taken at that altitude will cost 140 lbs. (21 gallons) for every minute, so it is important not to take more delay than is actually needed. It's better to shave a few minutes off of any landing delay which is estimated when the aircraft is still far from the terminal area, in order to compensate for any over-estimation of the needed delay.

For example, if a medium-weight B727-225A on a standard temperature day must take a minute of delay closer in to the terminal at only 5,000 feet, instead of at 31,000 feet, the fuel penalty is only 20 lbs. (2.9 gallons). If on the average the high altitude estimate, made while the aircraft is still 30 minutes from the runway, is right only half the time, then the aircraft which shaves a minute of possible estimation error off of every high altitude delay will save 20 gallons when the estimate is high by one minute, and will lose about 3 gallons when it is correct, relative to another aircraft which takes all of the estimated delay at high altitude. When the high altitude estimate is low by one minute, both aircraft will take the same fuel penalty whenever that error is detected and corrected prior to landing.

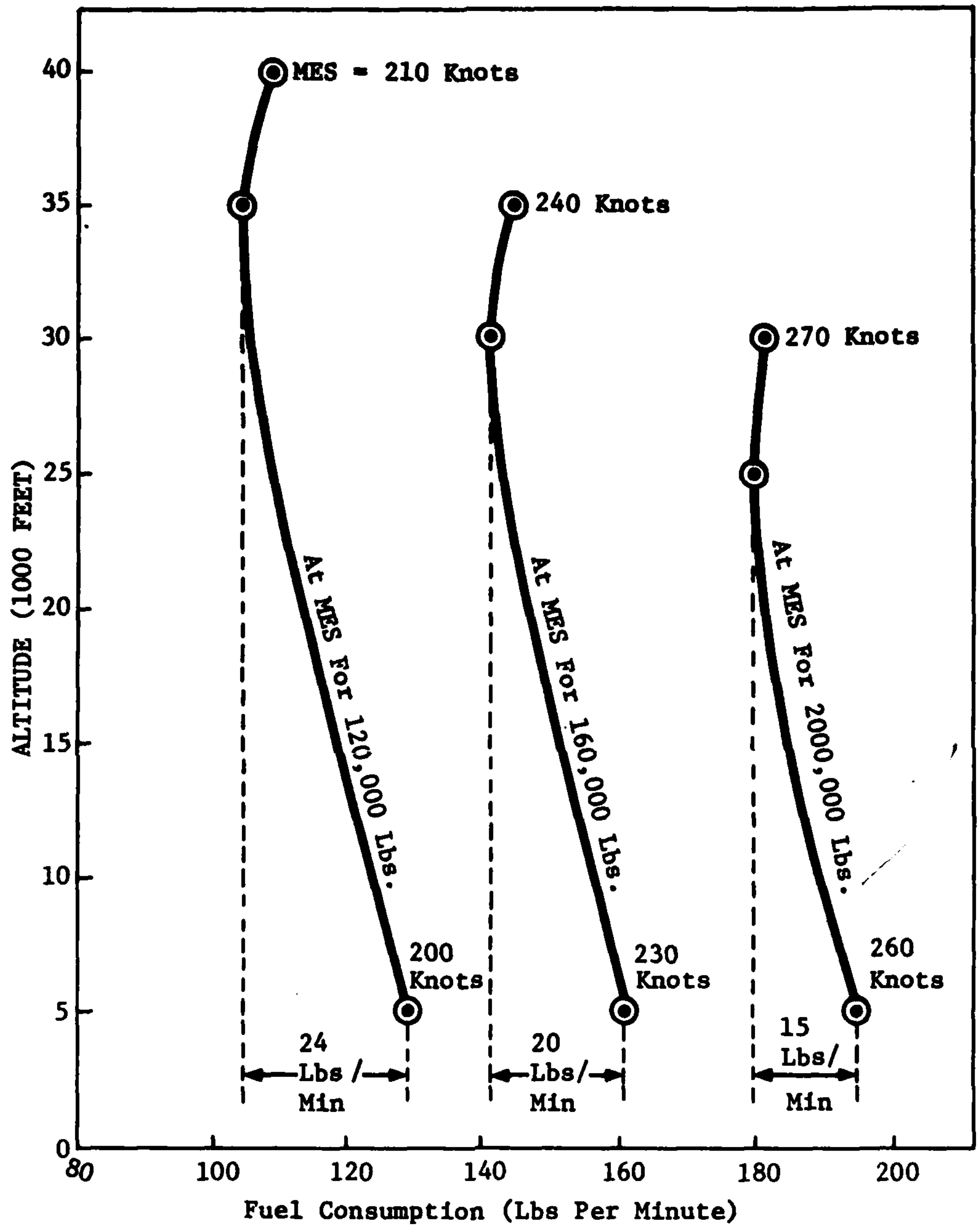
Clearly, when absorbing delay, it is more important to fuel efficiency that the amount of delay taken is no more than is actually necessary, than it is to take all of the estimated delay at high altitude. This is why the cardinal rule for en route metering should be: at the time a plan to delay a flight is to be translated into a specific control maneuver (speed reduction, path-stretching vector, or a hold), the maneuver should be calculated to absorb only that portion of the estimated delay that is certain to be needed. Under-estimation of the delay is permissible so long as the delay absorption capacities of downstream control positions are not exceeded.

With regard to the type of maneuver used to absorb a delay, it is best not to add extra miles to the route if it can be avoided. This means that the sooner the delay can be estimated (and discounted for any prediction errors), the better, since



Source: Reference 1

FIGURE 2-5
FUEL CONSUMPTION PER MINUTE IN CRUISE AT DIFFERENT ALTITUDES (FOR A B727-225A @ 160 KLBS, ZERO WIND, STANDARD DAY)



Source: Reference 1

FIGURE 2-6
FUEL CONSUMPTION AT MAXIMUM ENDURANCE SPEED VS. ALTITUDE
(FOR A B727-225A, ZERO WIND, STANDARD DAY)

along-course speed reductions can potentially be used in lieu of vectoring or holding.* If some of the delay can be estimated reasonably well prior to departure, so much the better, since little or no fuel needs be burned to absorb a delay before departure.

En route path-stretching and holding become necessary when landing delays are not known until it is too late to absorb them in any other manner.

Some terminal area path stretching capability is necessary for final sequencing and spacing. Terminal area holding is sometimes necessary when reductions in runway capacity occur unexpectedly.

* The lower limit is established by the Maximum Endurance Speed schedule for that aircraft. At FL350, the time controllability in a medium-weight B727-225A between the LRC and MES speed schedules is about 1 second per nautical mile; at FL250, it is about 2 seconds per nautical mile.

3. WASHINGTON CENTER CASE STUDIES

The following are examples of altitude and route restrictions commonly imposed by the Washington ARTCC. These examples were picked with the assistance of area specialists at the center in late 1980. These procedures were still in use in the fall of 1981 when this report was prepared for publication. These examples fall into one of two classes:

1. Procedurally-imposed restrictions: Those restrictions that are routinely applied to every qualifying aircraft in the manner prescribed by the procedures.

2. Ad hoc restrictions: Those created and invoked at the controller's descretion to resolve separation uncertainties. Often these involve one or more flights transitioning in altitude.

It was possible to estimate fuel savings for the examples in the first class, but not for those in the second class.

3.1 High Altitude Sectorization in the Washington Center

As of November 1980, there were 15 sectors established in the Washington Center to control traffic in the high altitude route structure - see Figure 3-1. The discussion of the procedurally imposed route and altitude restrictions in the examples is keyed in part to these sector boundaries.

3.2 Washington Metro Area Arrival Restrictions for Turbojets Arriving from the West or South

As illustrated in Figure 3-2, turbojet aircraft arriving from the west or south and expecting to land within the Washington DC area are all cleared to cross the arrival fix SABBI*, level at 10,000 feet. When landing to the north, those aircraft are also instructed to cross SABBI at 250 knots IAS. The altitude restriction at SABBI restriction does not change with a change in runway configuration, in order to keep the coordination simple between Washington Approach Control and Washington Center.

Prior to SABBI, all Washington area arrivals are cleared to cross either the Gordonville VA VORTAC (GVE) or the Richmond VA

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* SABBI is defined as an intersection 30 DME miles south of the DCA VORTAC on the 193^{o} radial (same as V376).

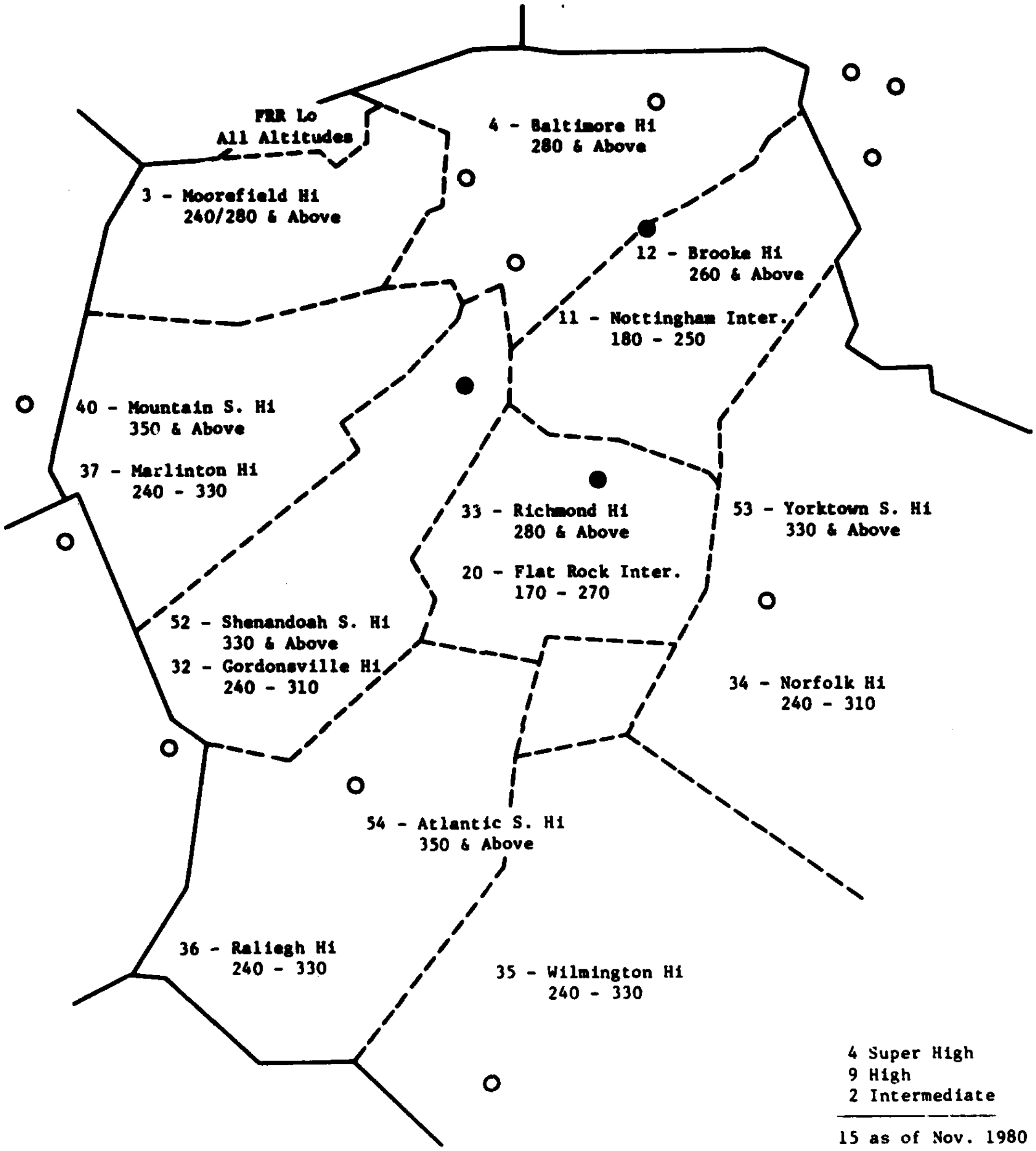
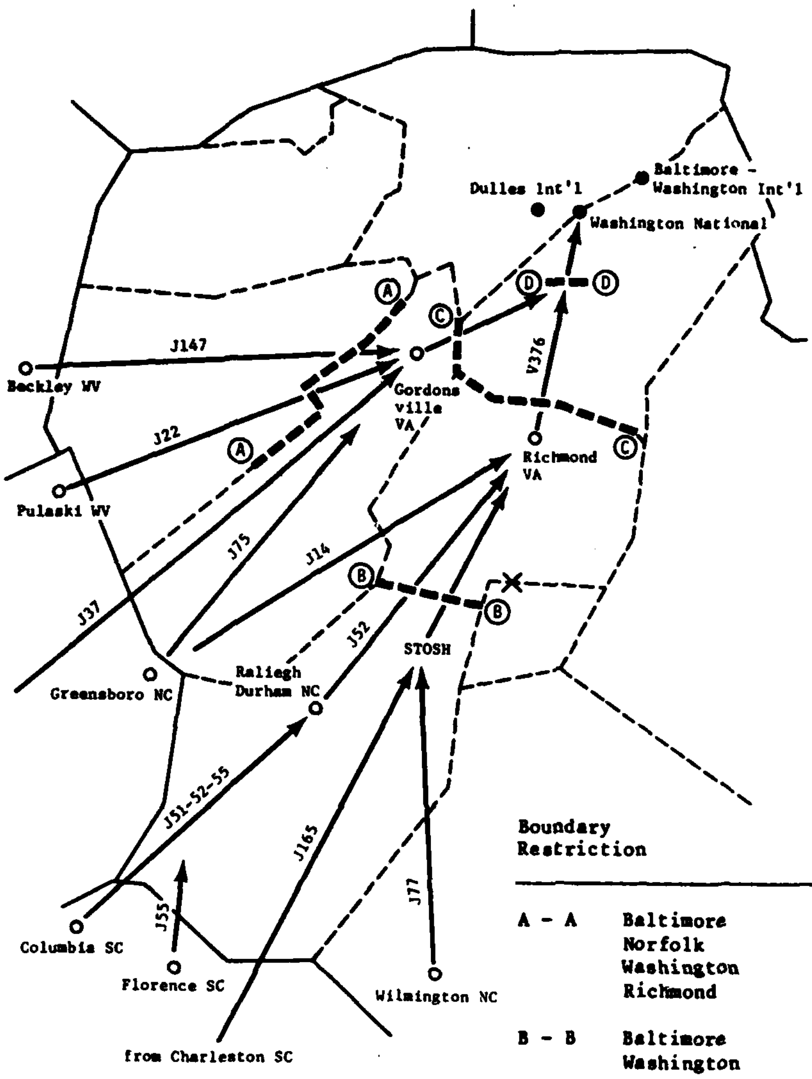


FIGURE 3-1
WASHINGTON HIGH ALTITUDE SECTORS



Boundary Restriction		Destination	Restriction
A - A	Baltimore	Cross at/below FL290	
	Norfolk	Cross at/below FL290	
	Washington	Cross at/below FL230	
	Richmond	Cross at/below FL230	
B - B	Baltimore	Cross at/below FL270	
	Washington	Cross at/below FL270	
C - C	Baltimore	Cross at/below FL250	
	Wash. National	Cross at/below 17,000'	
	Wash. Dulles	Cross at/below 15,000'	
D - D	Wash. National	Cross SABBI @ 10,000' level. When landing north, cross SABBI at 250 knots IAS.	
X	Baltimore Washington	Clear via STOSH (J77..J165)	

FIGURE 3-2
WASHINGTON METRO AREA ARRIVAL RESTRICTIONS FOR TURBOJETS FROM THE WEST AND SOUTH

VORTAC (RIC), in accordance with the procedural altitude restrictions indicated in the figure. These restrictions are imposed to segregate potentially conflicting traffic flows from each other and to minimize the number of sectors penetrated. This helps to distribute and balance control workload among sectors and to minimize the number of frequency changes required of the pilots.

In addition to the altitude restrictions above, Washington area arrivals via Wilmington NC are typically cleared via the STOSH intersection (...J77.STOSH.J165...), rather than being cleared direct via J40. This is done, in part, so that such arrivals can be merged by the Raliegh High sector with any other Washington area arrivals before they are handed off to the Flat Rock Intermediate sector.

3.2.1 Fuel Burn Penalties Associated with the Arrival Restrictions for Turbojets from the South

Depending upon the desired cruise altitude and descent profile for a given flight, the procedural altitude restrictions described above can extract a significant fuel penalty. For example, Figure 3-3 illustrates the nominal descent profile for a typical turbojet transport arriving Washington National from Miami. In this case, the desired cruise altitude is FL330 and the desired descent profile is "idle clean", descending at 350 knots IAS after crossover. If all the procedural altitude restrictions are imposed, the descent profile would follow the solid line. If the restrictions could somehow be removed without sacrificing safety, the descent profile would follow the dotted lines.

Differences in the fuel burns between the two profiles occur whenever given segments are flown at different altitudes. In addition, those flights arriving via Wilmington NC (ILM) and vectored via STOSH also suffer a small penalty by flying some additional miles farther than the direct route from ILM to SABBI. These fuel penalties are listed in Table 3-1. See Appendices B and C for the details of calculation.

Table 3-1 shows that the two procedural altitude restrictions at the south and north boundaries of the Flat Rock Intermediate sector impose a fuel penalty of about 31 gallons for every typical flight arriving Washington via Richmond. In addition, the SABBI intersection restriction imposes a fuel penalty of about 34 gallons whenever DCA is landing to the south. This occurs because the typical aircraft flys an additional 20 miles

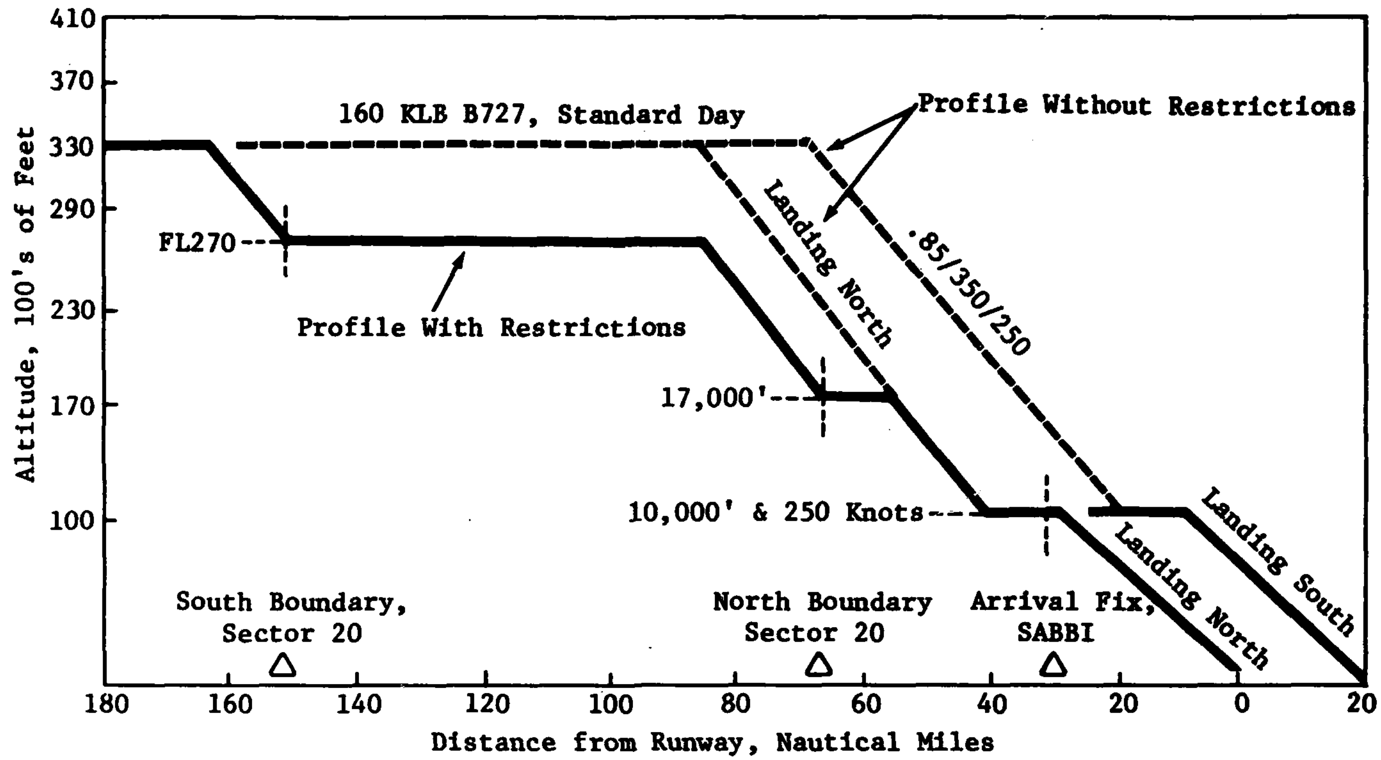


FIGURE 3-3
ALTITUDE PROFILES FOR WASHINGTON NATIONAL AIRPORT ARRIVALS

TABLE 3-1

SUMMARY FUEL PENALTIES FOR RIC..SABBI..DCA ARRIVALS

Vertical Profile Restrictions	Fuel Penalties per Flight Idle Thrust,
o 270 @ FAK Int. Boundary	22.8
o 170 @ EPICS	8.4
Landing North from Other Than ILM (e.g., CHS*)	31.2 gals. (2.0% from CHS)
o 100 @ SABBI	+34
Landing South from Other Than ILM (e.g., CHS*)	65.2 gals. (4% from CHS)
o STOSH Dogleg	+16.8
Landing South from MIA..ILM* (-34 gals.)	82.0 (3.0% from MIA)
Landing North from MIA..ILM*	48.0 gals. (1.8% from MIA)

Number of Flights (Friday, 10 October 1980

VPS, ATL, CLT, ...	Routes West of J165	8
TPA, MCO, JAX, SAV, CHS, ...	CHS.165	15
MIA, PBI, ...	Via ILM	16
		39

*MIA..DCA = 800 N. Miles
CHS..DCA = 400 N. Miles

at 10,000 feet to reach the runway threshold, when it might have flown those additional 20 miles at FL330, had this altitude restriction not been in effect. For a typical flight which departed Charleston SC for Washington DC, these fuel burn penalties together represent 4% of the total trip fuel burn.

For those flights that fly the dogleg via STOSH, the extra miles add 16.8 gallons to the fuel penalty. For a typical flight which departed Miama FL for Washington DC, this dogleg penalty, together with the previous altitude penalties, represents between 2% and 3% of the total trip fuel burn, depending upon whether Washington is landing to the north or to the south.

Also shown in Table 3-1 is the number of flights which arrived Washington via Richmond on Friday, 10 October 1980, as determined by an analysis of flight progress strips. In every case, the altitude restrictions were applied. In most, but not all cases, the flights arriving via Wilmington NC (ILM), were routed via STOSH. In a few cases, direct routings to RIC were coordinated.

3.2.2 Potential Traffic Conflicts with Washington Arrivals from the South

Figure 3-4 illustrates the major high altitude traffic flows which potentially conflict with Washington DC arrivals via Richmond VA. Northbound traffic over Gordonville VA (GVE) remains at high altitude if it is proceeding to New York and points north, otherwise it is descended and merged with the other Washington DC arrivals via Richmond VA (RIC). Thus, the overflight traffic has altitude separation relative to the Washington arrivals via Richmond. In-trail spacing of both the GVE and RIC arrivals must be achieved before the merge point at SABBI.

The major source of potentially conflicting traffic to Washington DC arrivals is that proceeding southbound from Kenton, MD (ENO) to RIC via J14. As illustrated in the figure, due to the restricted areas serving Patuxent Naval Air Station (R4002, 4005, 4006) and the off-shore warning areas (W108, W386), southbound traffic out of New York only has two choices: Kenton to Richmond (ENO.J14.RIC) or Coyle NJ to Norfolk VA (CYN.J79.ORF).

From this perspective, one can begin to understand the reasons for the procedural altitude restrictions for arrivals entering the Flat Rock Intermediate sector. The restrictions insure that

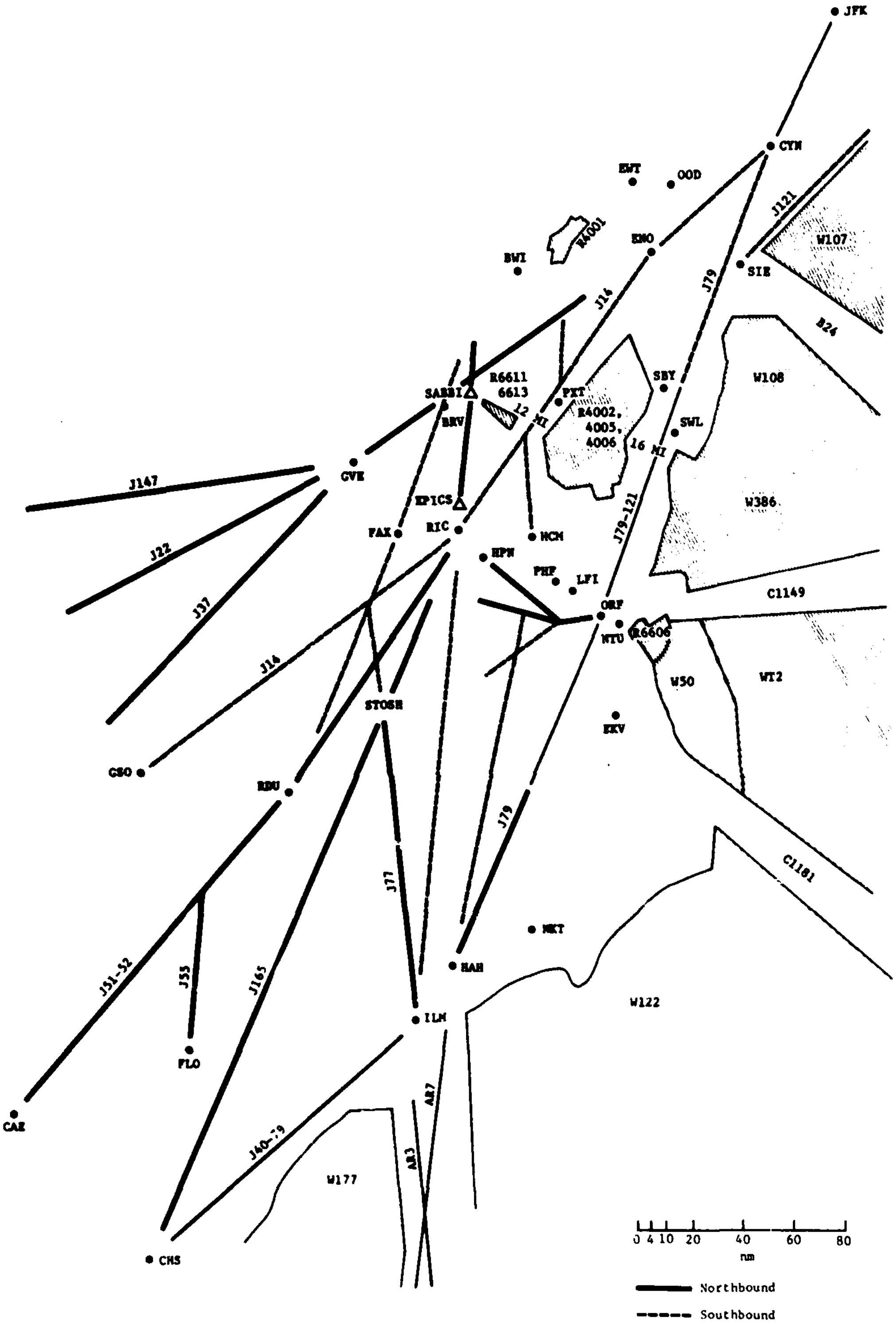


FIGURE 3-4
HIGH ALTITUDE FLOWS OVER RICHMOND, VIRGINIA

northbound arrivals are descended to altitudes below southbound overflights before reaching the Richmond area, with the Richmond High sector taking responsibility for the overflights, and Flat Rock Intermediate sector taking responsibility for the Washington area arrivals. This both assures segregation of opposite way flows and divides the ATC workload between the two sectors. But to the extent that there may not exist any potential conflicts with opposite way traffic when an arrival traverses the Richmond area, such procedural altitude restrictions impose an unnecessary fuel penalty.

To find out how necessary such procedural restrictions are from the standpoint of potential traffic conflicts alone, an analysis of a busy day's flight progress strips was made. The results are summarized in Table 3-2. In brief,

1. During the 8 hours of the midnight shift, only one aircraft arrival via SABBI, while only 3 aircraft proceeded southbound via J14 over RIC. This suggests that the probability of a conflict between that one arrival and any one of the three southbound flights was extremely small.

2. During the day shift, business picked up. Over the 8 hours, there were 24 northbound arrivals via RIC, while there were 71 potentially competing southbound overflights via J14. However, the most popular cruise altitude for the northbounds was FL330, and only 29 of the southbounds were (at or) below this altitude. Disregarding the actual time distribution of these flights, the average southbound rate was only about 4 flights per hour. This suggests that, in principle at least, there existed many opportunities for descending a given arrival flight through the altitudes of lower opposite-way flights without loss of horizontal separation. Such descents could be made either along the centerline of the shared route or on a parallel offset to that route, should possible loss of horizontal separation be a factor.

3. During the evening shift, the average potential conflict rate is roughly half that of the day shift, suggesting even more opportunities for an unconstrained descent into Washington.

The point is to suggest that the system imposes such procedural altitude restrictions for reasons other than too many aircraft trying to occupy a given airspace. If airspace occupancy alone

TABLE 3-2

SABBI ARRIVALS VS J14 SOUTHBOUNDS

Shift	Time, EDT	SABBI Arrivals Before Descent	Potential Competitors Over Shift	Maximum Average Conflict Rate
Mid	0-8	1 @ 370	3 Below 370	1 Flight per 3 Hours
Day	0-16	24 Total Flights	71 Total Flights	
		8 @ 370	66 Below* 370	8 Flights per Hour
		12 @ 330	29 Below* 330	4 Flights per Hour
		1 @ 290	9 Below* 290	1 Flight per Hour
		2 @ 270	2 Below* 270	1 Flight per 4 Hours
		1 @ 250	0 Below* 260	0 from J14 Southbounds
Eve	16-24	14 Total Flights	28 Total Flights	
		2 @ 370	26 Below* 370	3 Flights per Hour
		12 @ 330	Below* 330	2 Flights per Hour

*Includes all flights transitioning to/from the next higher southbound altitude.

were the criterion, altitude restictions for the purpose of separating actual aircraft movements would be the exception, rather than the rule.

For more details on this traffic analysis, see Appendix D.

3.3 Route Restriction on Norfolk to Chicago Flights

Figure 3-5 illustrates some alternative routes for flying at high altitudes from the Norfolk VA area to Chicago IL. The ATC-preferred route is the dogleg via Charleston, WV, shown as solid route "A". The user-preferred route is the direct route via Gordonsville VA to Fort Wayne ID, shown as dashed route "C". The difference between the two routes for a typical turbojet transport in terms of fuel is 182 extra gallons for route A - see the analysis details in Appendix E.*

3.3.1 Potential Traffic Conflicts with Norfolk to Chicago Flights

As illustrated in Figure 3-5, the traffic which is potentially in conflict with any turbojet climbing out over the direct route from Norfolk to Chicago is predominantly that departing the Washington DC area and climbing out over Casanova VA for Chicago or over Beckley WV for points west and southwest. If allowed to fly direct, altitude separation cannot be guaranteed in advance, and the sector boundaries are so aligned that any actual conflicts between the Casanova departures and the Norfolk area departure cannot be resolved by any one sector alone. In today's system, it would require (1) a manually-coordinated clearance across a sector boundary, which (2) would involve climbing aircraft in a crossing situation whose climbout profiles are poorly known at the time the coordination would be required. The procedural route restriction via CRW avoids those two problems by ensuring that (1) altitude separation will always apply at the intersection with the Beckley-bound departures and by (2) moving the merge point with the other Chicago-bound departures to a more easily handled location.

Other traffic of somewhat lesser concern is that arriving the Washington DC area via Gordonsville VA from Beckley WV and Pulaski VA; also, southeast-bound arrivals for the Norfolk area

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* The compromise route "B" is one that had been under consideration as a replacement for "A", but it was later discarded since current navaid sites couldn't support it.

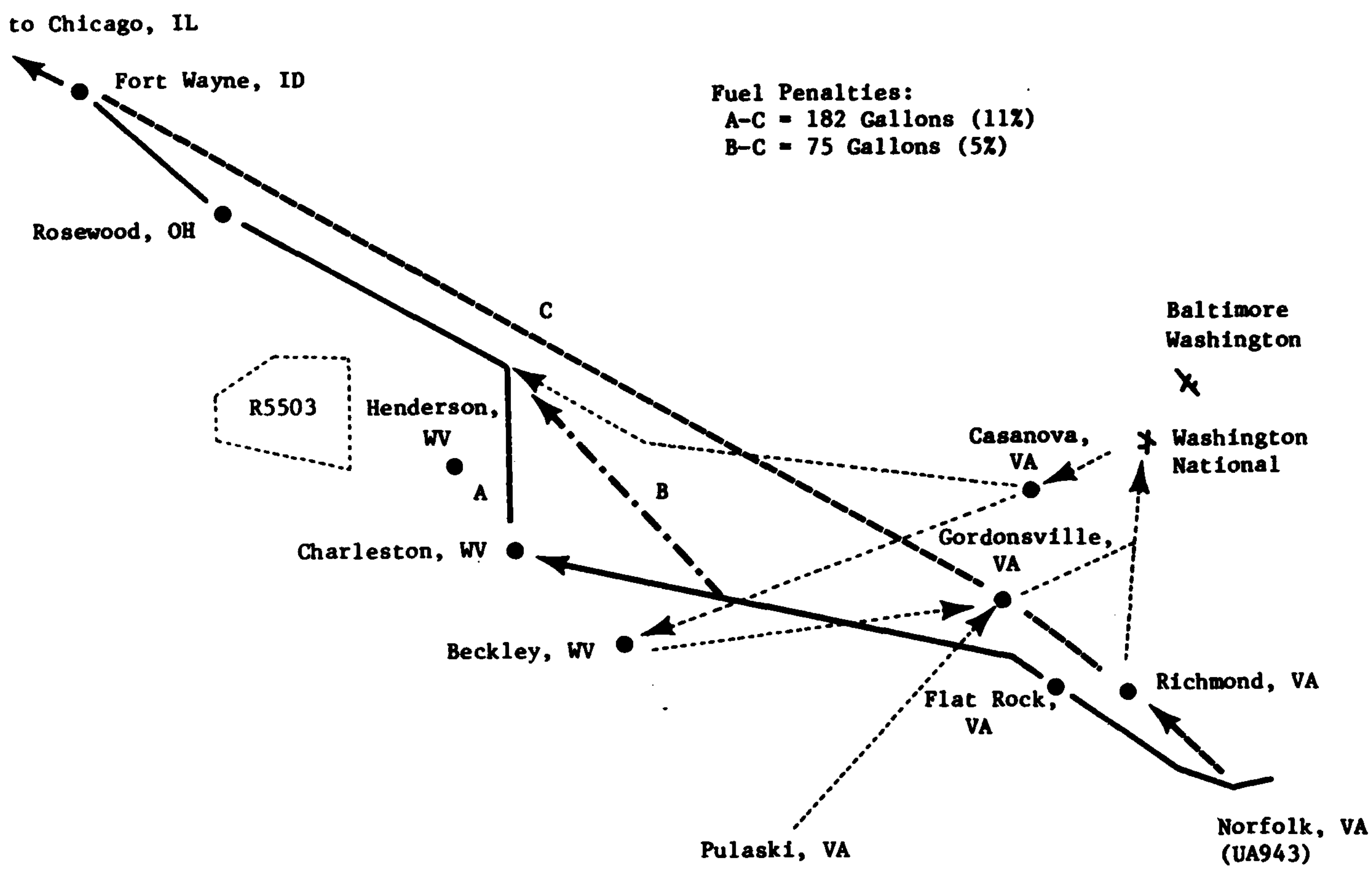

FIGURE 3-5
ROUTE RESTRICTION ON NORFOLK TO CHICAGO FLIGHTS

are possible conflicts. From a procedural viewpoint, Route "A" provides better vertical separation from the former and better lateral separation from the latter.

An analysis of the flight progress strips for Friday, 10 October 1980, which is summarized in Appendix F, reveals that a total of 11 flights were proposed to depart the Norfolk area bound for Chicago that day. Of these, 8 actually departed. All 8 flights were cleared via one of the these two navigatable routes:

Departure Airport	Cleared Route*
Richmond(RIC)	...FAK.J24.CRW.J85.(PKB).J149.FWA...ORD
Norfolk(ORF)	or
Patrick Henry(PHF)	...FAK.J24.CRW..HNN..ROD..FWA...ORD

Table 3-3 lists the number of flights that departed via Casanova each hour on that same busy day (Friday, 10 October 1980). It shows that 1 to 2 dozen departures per hour were typical. At that rate, the chances that a Norfolk departure on a direct route clearance might require some control action to assure separation are about "50-50". In the event of a conflict, either a simple altitude restriction to cross above/below the crossing aircraft's path, or a simple vector to pass behind or to join in-trail with the other aircraft, would probably be all the control action that would be needed. One problem to be solved is getting the need for such a control action predicted and coordinated in a timely way, without increasing the workload on the sector handling the Casanova departures. A second problem that may have to be solved is to detect when the predicted traffic relative to the direct route is such that a simple interim altitude assignment or a simple vector might prove insufficient, thus requiring the non-direct route clearance via CRW.

3.4 Estimating the Annual Fuel Burn Penalties from Existing Procedural Restrictions

The two proceeding examples of procedural route and altitude crossing restrictions applied to:

1. Washington DC Arrivals via Richmond, and
2. Norfolk Area Departures to Chicago

* Route A in the figure corresponds the first route above. The second route above cuts the corner between Charleston, WV (CRW) and Rosewood OH (ROD).

TABLE 3-3

CASANOVA DEPARTURES, HOURLY RATES

10 October 1980

GMT TIME	EDT TIME	ADW	BWI	DCA	IAD	TOTAL
		By Airport				
1100	0700	1	1	10	4	16
1200		2	3	10	6	21
1300		4	1	6	7	18
1400		1	1	10	4	16
1500		-	4	8	3	15
1600		2	2	5	3	12
1700		3	2	10	1	12
1800		1	-	10	1	12
1900		1	5	14	5	25
2000		-	2	10	2	14
2100		1	3	12	7	23
2200		1	4	8	8	21
2300	1900	-	-	12	4	16
0000			1	4	-	5
0100			-	2	-	2
02-1000			4	5	3	12
		17	33	136	59	245

Source: Reference 8.

Since these restrictions are routinely applied to all, or nearly all, such flights, it is possible to estimate the annual impact of these penalties - see Table 3-4.

The first column lists the per-flight fuel penalty previously computed. The second column lists the number of daily flights counted on Friday, 10 October 1980. Since this was an exceptionally busy day for the Washington Center (6100 handles, which is 97% of the center's all-time high of 6300 handles), the third column estimates the annual number of such flights as 300 times the daily rate for this particular Friday.

The table also assumes that half of all landings at Washington National are conducted landing to the south. Therefore, half of all such arrivals also pay the price in fuel imposed by the "10,000 feet at SABBI" restriction.

On this basis, the annualized fuel penalty from these two cases of procedural restrictions alone is close to one million gallons annually.

3.5 Fuel Burn Penalties Associated with Subjective Controller Decisions

The preceding examples dealt with procedurally applied route and altitude restrictions. Because they are routinely applied (clearances which take exception to these procedures must be individually coordinated), it is easy to estimate the annual fuel penalty by multiplying an average per-flight penalty times the number of flights which satisfy the conditions which activate the rule.

The following example illustrates another class of fuel penalties which are not so easy to quantify.

Figure 3-6 illustrates a range of climb profiles for a handbook B727-225A operating in no wind conditions and using a particular climbout speed schedule. If it is a medium weight aircraft of about 160 Klbs on a standard temperature day, it can reach FL330 in about 140 n. miles. On a cold day, that same aircraft could reach that same altitude in about 100 miles. On a hot day, it would take 200 miles to reach FL330. On the other hand, if the aircraft is only lightly loaded on a standard temperature day, it could reach FL330 in only 60 miles.

Assume that a controller has an overflight level at its assigned altitude of FL330, and then he accepts a departure climbing out

TABLE 3-4

ESTIMATED FUEL PENALTIES OF EXISTING PROCEDURAL RESTRICTIONS

For Washington National Arrivals via SABBI
Norfolk Departures to Chicago via J14

	Gallons per Flight	Number Flights on 10-10-80	Estimated Flights Annually (x 300)	Estimated Arrival Fuel Penalty (Thousands of Gals.)
Washington National Arrivals via RIC				
Arrivals via CHS.J165 or Routes West	31.2	23	6900	215K
Arrivals via STOSH	48.0	16	4800	230K
		39	11,700	
SABBI @ 100 if Landing South	+34.0	39	5,850 (above/2)	200K
Norfolk Departures to Chicago				
J24 CRW Dogleg	182			
or				
MOL..PKB Dogleg	75	8	2400	180K to 437K
				825K to 1 Million Gallons Annually

1. Based on a preliminary analysis of data for Friday, 10 October 1980 (6100 Handles = 97% of Highest Peak Day) for Washington Center).

2. Penalties for Idle Descent, Clean.

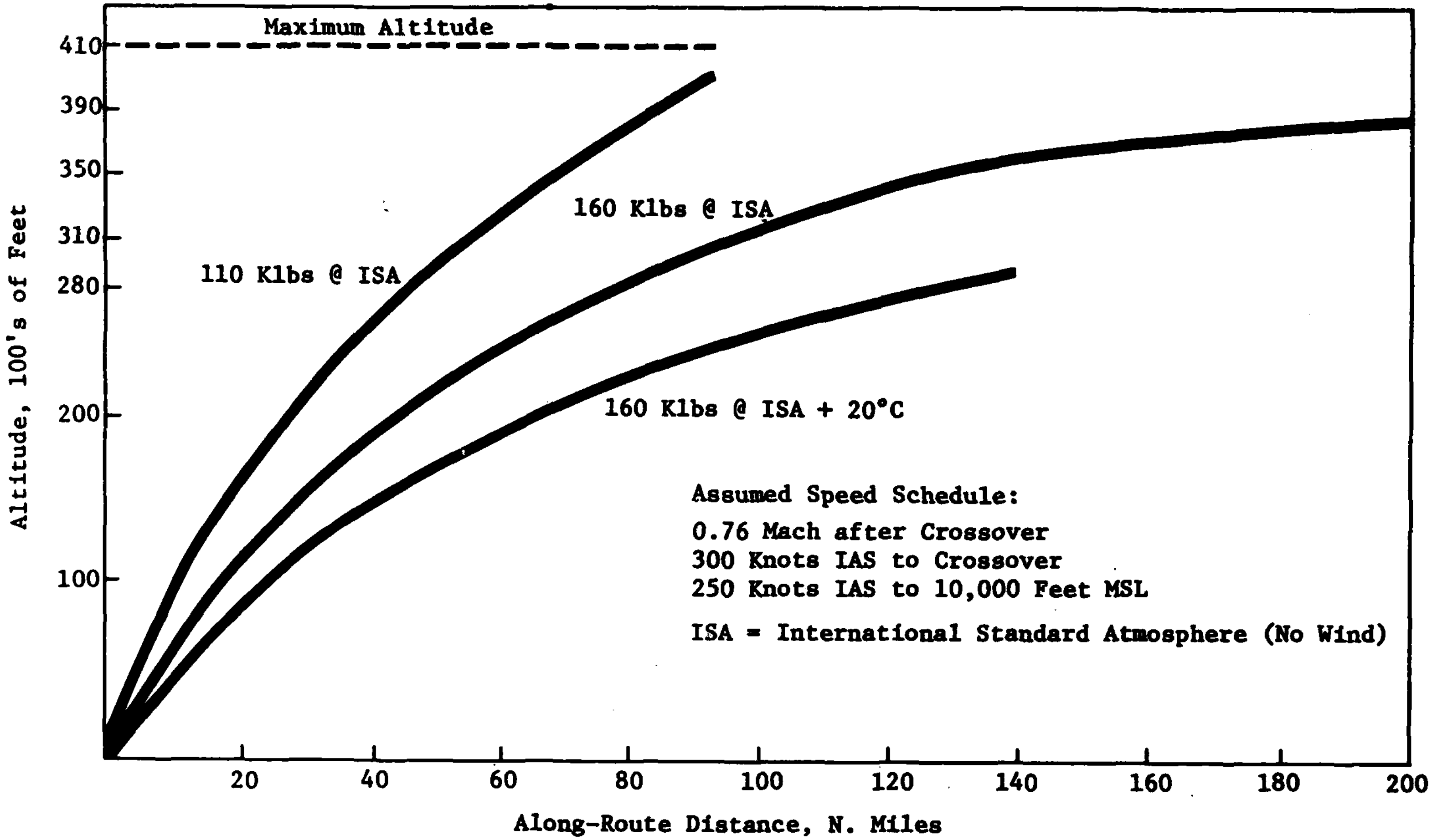

FIGURE 3-6
TYPICAL CLIMB PROFILES FOR A B727-225A

for an altitude at or above FL330 on a course which intersects that of the overflight. The question is: Will the controller be able to rely on vertical separation, given that horizontal separation has been predicted to be lost near the intersection? The real answer is: a controller in today's system has a hard time answering that question. Some of the reasons include:

1. He typically doesn't carry the precise climb characteristics of each aircraft type and subtype around in his head, and the NAS Stage A system doesn't compute climb profiles for him either.

2. If this is the first departure out on his watch, he probably isn't mentally calibrated yet on how the winds and temperatures currently aloft are biasing climbout performance of like aircraft types.

3. In today's system, he has little or no knowledge of what climbout speed schedule this particular pilot will use, anyway. And he doesn't know the gross weight of the aircraft, unless he happens to ask the pilot. So he really doesn't have much to go on, even if he could estimate climb profiles in his head.

Given such limitations, it is not suprising that most controllers are very wary of using vertical separation when a climbing turbojet is involved. They are even less inclined to use vertical separation when the potential conflict is between two climbing turbojets on crossing courses.

This is exactly the problem facing the controller at the Flat Rock Intermediate sector whenever he has a departure climbing out of the Norfolk VA area, westbound, which is potentially competing with one or more departures from the Washington DC area, southbound, and climbing out over the Brooke VA VORTAC - see Figure 3-7. The flying distance for both departures to the common intersection over the Flat Rock VA VORTAC is about 90 miles. And the current computer system gives the controller very little assistance in advance in predicting whether horizontal or vertical separation will be preserved during the crossing.

Due to the shape of the sector and typical handoff procedures, the controller at the Flat Rock Intermediate sector will gain control of the Norfolk departure in time to resolve any conflict through an interim altitude crossing restriction, or possibly a vector, though there isn't much room to the north for the latter. Consequently, the need for, and the severity of, the

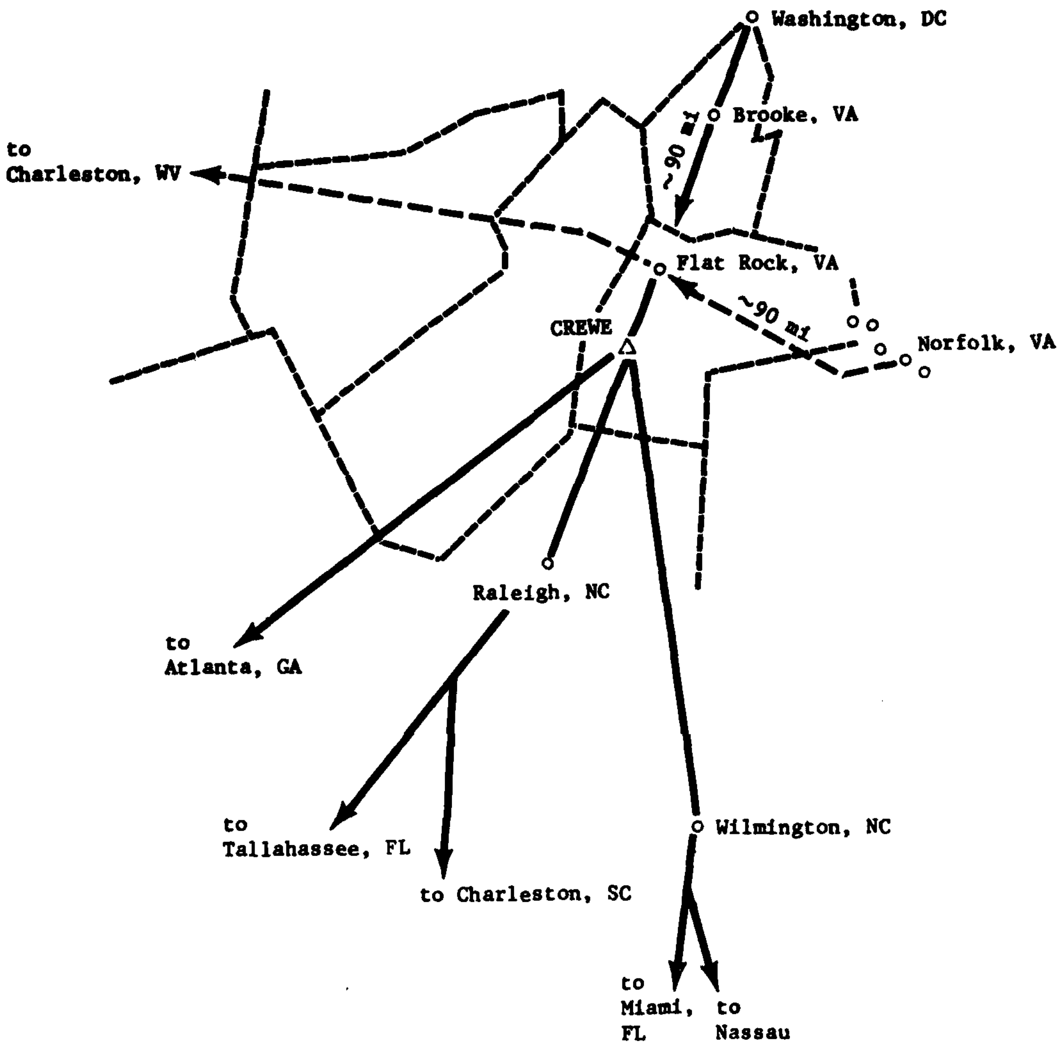

FIGURE 3-7
DEPARTURE CONFLICTS OVER FLAT ROCK, VIRGINIA

commonly used altitude crossing restriction is strictly up to the controller's judgement. A common rule is to note the reported mode C altitude for the lowest Brooke departure that may be a problem, and assign that altitude as an interim crossing restriction to the Norfolk departure.

Naturally, safety comes first, so this conservatism in the present system is probably justified. But from the perspective of actual flight movements, it is a safe bet that many such restrictions are either unnecessary or are overly protective.

First, more accurate prediction of longitudinal progress would often show that horizontal separation would not have been lost, and the use of vertical separation was unnecessary. Second, vertical separation may have been achieved with only a modest adjustment in climb rate by one of the aircraft.

A computer system could be provided the necessary data from which reasonably accurate predictions of climb performance could be made. Such a system could be used to avoid making unnecessary or unnecessarily harsh restrictions to restore conflicts when they occur.

Such situations can be found throughout the ATC system, but the fuel penalties they impose are very difficult to quantify because of the subjective factors involved.

4. REVIEWS OF OTHER CASE STUDIES

In order to expand the perspective of this study, the author has reviewed the data and results of two other recent reports. The details of these reviews are found in the following appendices:

Appendix A: A Review of "Operation Free Flight"
Appendix G: A Review of the Northeast Area Procedural Study

Both reports provide data on the degree of freedom airspace users have in requesting, and getting cleared by ATC to fly, the routes and altitude profiles they desire.

Both reports were produced by FAA's Air Traffic Service as part of their effort to improve the ATC system's ability to accommodate more fuel-efficient IFR flight. Both reports are very revealing about current problems in this regard.

4.1 Conclusions Drawn from a Review of Operation Free Flight

Operation Free Flight was an "operational evaluation of RNAV direct route flight plan filing in today's national airspace system". The project was conceived and managed by FAA's En Route Procedures Branch (AAT-330). See Appendix A and Reference 6 for details.

Table 4-1 summarizes what, in this reviewer's opinion, constitute the key points to be made. These points lead to further observations:

1. Relative to fuel-optimal routes, flying the established airway structure in the U.S. may impose an average 2% fuel penalty: When great circle routes are the most fuel-efficient routes to fly, the published airways that approximate them were found to impose about a 2% fuel penalty on the flights participating in the evaluation. Presumably, this same penalty would apply to all users unable to fly the more direct route between filed departure and arrival transition fixes. While no data was collected to confirm or refute the following, it is probably reasonable to assume that a similar penalty would obtain when the most fuel-efficient route is a route other than a great circle route and when the user attempts to approximate it using the present airway structure. (This presumes that the user's flight planning process has a sufficiently accurate wind aloft forecast to determine what the fuel-optimal route really is.)

TABLE 4-1

ROUTE RESTRICTIONS FOUND AND OTHER KEY POINTS FROM "OPERATION FREE FLIGHT"

The applicable sections of Appendix A are cited in parentheses

Relative Fuel Efficiencies in Flying Great Circle Routes:

User requested other than a great circle route in about 2 out of 3 cases, presumably due to forecast winds (A.3, #2).

When a great circle route was requested, ATC granted that great circle route in a majority of cases (A.2, #1).

Flying great circle routes did not always prove as fuel-efficient as expected (A.2, #5).

Despite the above, when great circle routes were requested and granted, an average 2% fuel saving was reported, relative to the fuel burn expected via the airways which would otherwise have been requested (A.2, #4).

Actual or Potential ATC Constraints to Great Circle Flights:

The length of the unconstrained great circle routes flown during Operation Free Flight was (A.3, Table A-11):

Averaged by routes (39): 1000 miles
Averaged by flights using (1924): 1130 miles

The user does not have his choice of routes within 150 miles or so of major terminal areas (A.3, #3).

The routes imposed by the ATC system within 150 miles or so of major terminal areas often add extra flying miles (A.3, #4).

Aircraft controllers often unwittingly contributed to the user's inability to follow a great circle route clearance (A.2, #2).

Design limitations of NAS Stage A.3 computer software had to be worked around (A.3, #5).

The stereographic projection system may not be the best coordinate system for representing great circle routes internally in the computer (A.3, #6).

2. The limited number and rigidity of the arrival and departure transition paths to and from major terminal areas in the U.S. impose additional fuel penalties: Though no attempt was made to estimate these penalties imposed on the flights participating in Operation Free Flight, such penalties have been estimated for the Washington ARTCC and New York ARTCC case studies (Section 3 and Appendix G, respectively). Such penalties are shown to be significant, in terms of the extra gallons of fuel burned. They are also significant as a percentage of total trip fuel burn for some (e.g., short-haul) flights.

3. The ATC computer system may need redesign to better support optimal route flying over the U.S.: Both functional limitations and less-obvious technicals shortcomings in the current NAS Stage A.3 computer system design will probably constrain the opportunities for more optimal route flying in the future, unless changes are made. While not fully investigated during the evaluation period for Operation Free Flight, the following design concerns should be noted.

First, there is the inability to use the computer to negotiate the most fuel-efficient route and altitude profiles for departing and arriving aircraft, in a manner which transcends sector boundaries. Such an ability could reduce the need for the kinds of procedurally-imposed restrictions that were encountered by Operation Free Flight participants. The problem is basically to find a way to dynamically negotiate the best route and altitude profile for each aircraft, subject to separation and system capacity constraints and without creating controller workload.

Second, there is the question of how the flights paths over the earth's surface should be internally represented in ATC computers, in order to support flight plan route processing, the correlation of surveillance and tracking data, and to support clearance planning and control coordination functions. The scheme now implemented nationally is based on the stereographic projection system, augmented in certain cases by the gnomonic projection system. Both systems are "flat earth" approximations to what might be better represented in a spherical coordinate system. While there are ways to minimize the problems in the context of the present system design, other concerns remain. An investigation into the design tradeoffs involved is needed in order to make a wise decision for the advanced computer system (ACS) now being contemplated.

4.2 Conclusions Drawn from a Review of the Northeast Area Procedural Study

The Northeast Area Procedural Study (NAPS) was an in-depth analysis of current ATC procedures in the areas controlled mainly by the New York ARTCC and its associated terminal facilities. The study was sponsored jointly by FAA's Eastern and New England regions. See Appendix G and Reference 2 for details.

Table 4-2 summarizes what, in this reviewer's opinion, constitute the key points to be made. These points lead to these further observations:

1. Limitations in the functional capabilities of the current ATC system lead to fuel-inefficient procedural constraints: While the NAPS Committee worked diligently to minimize the fuel penalties of existing ATC procedures, they had to work within the constraints of the current system design. The result was that more fundamental changes were placed beyond the scope of serious consideration. For example, in no case was an altitude or route restriction removed. At best, the restriction was made somewhat less penalizing. At worst, the restriction was rationalized, but left unchanged.

2. Procedural route and altitude restrictions tend to hit hardest those flights which buck or cross the major flows: In order to give expedited service to those flights operating between the major terminal areas, route structures and crossing altitude restrictions are oriented accordingly. Route penalties of up to 27% and altitude penalties of up to 10%, in terms of extra total trip fuel, would still exist for some short-haul aircraft, even if all NAPS recommendations were implemented.

   Similarly, flights from the Caribbean to both Newark and Kennedy are severely penalized by altitude crossing restrictions because they cut across more frequently used north-south transition routes. Here the severity of the penalty is masked when it is expressed as a percentage of total trip fuel burn, because of the size of that total burn (about 4800 gallons). In gallons, the penalties on a representative turbojet were estimated to be:

TABLE 4-2

SOME ROUTE AND ALTITUDE RESTRICTIONS ADDRESSED BY THE MAPS STUDY

The applicable sections of Appendix G are cited in parentheses

General (G.1, G.2, plus below)	MAPS Recommendation or Follow-Up	Remaining Fuel Penalties?
Inflexibility of the dedicated arrival route system (G.3)	RAMP Committee established	Changes not decided
Inflexibility of the "Preferred IFR Route" system (G.4)	Review/revise published hours	Yes
Altitude restrictions on short haul flights (G.6)	Raise center boundary crossing restrictions	Yes (up to 10%)
Route restrictions on short haul flights (G.6)	No changes recommended	Yes (up to 27%)
Route and altitude restrictions, low altitude en route (G.7)	Expand use of existing NE-SW route	Yes
	Add a low level north-south route west of NY TCA	Yes
	Add an east-west pair of routes for LI airports	Yes
Specific		
Altitude restrictions on LaGuardia Departures via Solberg (G.5)	Delegate shelf to departure sector, traffic permitting	Yes (3%)
	Raise ceilings of low altitude sectors	
Circuitous routes for Kennedy arrivals from west/northwest (G.8)	More direct vectors in light traffic	Yes
Altitude restrictions on Newark arrivals from Caribbean (G.9)	None that helped fuel savings	Yes (4%)
Altitude restrictions on Kennedy arrivals from Caribbean (G.10)	Raise crossing restriction by 2000 ft.	Yes (1%)
Departures bottleneck at the LaGuardia departure position (G.12)	Add a coordinator for higher altitudes	outcome unknown
Departures bottleneck in the Solberg sector (G.13)	Establish a new departure route	effect unknown

	Fuel Penalty, After NAPS Gallons (% of total trip burn)
San Juan to Newark	85 to 190 (2% to 4%)
San Juan to Kennedy	19 to 82 (0% to 2%)

3. Data on actual aircraft movements suggest that procedurally-imposed restrictions are overly protective: For example, data collected on traffic potentially conflicting with LaGuardia to Washington, D.C. short-hauls suggest that the desired altitudes could be time-shared between these potentially conflicting aircraft, rather than being procedurally denied to the short-hauls. To accomplish such sharing of altitudes, without either sacrificing safety or increasing controller workload, will likely require some automated conflict prediction and clearance coordination tools not available in the current NAS Stage A.3 computer system.

4.3 Summary of Why ATC Restrictions are Routinely Applied in the Current ATC System

All ATC facilities now establish routine procedures for the handling of IFR flights entering, traversing, and leaving their airspaces. Some procedures are more restrictive than others regarding the routes or altitudes that can be flown by aircraft with particular flight plans (points of departure/destination, requested cruise altitudes, etc.). Table 4-3 provides a generic summary of the most common types of restriction in use today.

All such restrictions are justified for reasons which can be categorized under one or more of the following headings:

1. The need for segregated arrival and departure corridors to/from a given airport complex, airport, or runway. Segregated arrival routes assure that those aircraft which are converging on a common destination are merged and descended in an orderly fashion to enter the final sequencing and spacing area.

   Segregated departure routes are typically defined as routes which bisect the angle between adjacent arrival routes. Such routes allow for the wide diversity in climbout performance which is found between aircraft, depending upon outside air temperature, aircraft type and weight, and the pilot's chosen climbout thrust/speed schedule.

TABLE 4-3

ROUTINELY APPLIED ATC RESTRICTIONS WHICH IMPACT AIRCRAFT FUEL EFFICIENCY

	Impacts on Fuel Efficiency		
	Extra Miles	Non-Optimum Altitudes	Non-Optimum Speeds
On Departure:			
Standard Instrument Departures (SIDs)	X	X	
Preferential Departure Routes (PDRs)	X		
Altitude Crossing Restrictions at Center/Sector Boundaries		X	
Speed Limit below 10,000'MSL			X
In Cruise:			
ATC Preferred Low Altitude Routes	X		
ATC Preferred High Altitude Routes	X		
4000' Vertical Separation Between Same-Way Flight Levels above FL290		X	
De Facto Cruise Altitude Restrictions on Short-Haul Turbojets		X	
Flow Rate Restrictions	X	X	X
On Arrival:			
Standard Terminal Arrivals (STARs)	X	X	
Preferential Arrival Routes (PARs)	X		
Altitude Crossing Restrictions at Center/Sector Boundaries	X		
Speed Limit below 10,000' MSL			X
Flow Rate Restrictions	X	X	X

Segregated corridors insure that arrival and departure operations to/from the chosen airport(s) can be conducted without significant interference from other aircraft with different destinations and/or points of departure.

2. The need to reduce controller workload: During busy periods, some control sectors could easily be swamped with more traffic than they could handle, given the tasks currently performed by the sector control teams in the exercise of their duties. One common method of coping with this problem has been to (1) split sectors into smaller jurisdictional units and then to (2) procedurally allocate different potential traffic flows to different sectors in order to distribute the workload. Routinely applied, or flow control initiated, route and altitude restrictions are the typical means of distributing traffic flows by sector.

3. The need to match demands for ATC services to available capabilities: Runways are demand-saturable. ATC computers and ATC control teams are demand-saturable. Also, airspace which contains severe weather activity can be considered saturable. Consequently, the system must try to anticipate excessive demands for service before they materialize and then deal with them, typically through restrictive measures. Flow rate restrictions, altitude restrictions, and route restrictions are the frequently used tools.

4. The need to reduce the uncertainties associated with planned flight profiles: The current ATC system has good knowledge of the planned horizontal route of all flights, fair knowledge regarding their expected ground speeds over those routes when at cruise altitude, good knowledge of current position and velocity, but only rudimentary knowledge of where aircraft will be in altitude during the climb or descent phases of flight. Procedural altitude crossing restrictions are a typical way of reducing these uncertainties, particularly where climbing turbojet aircraft cross over another frequently used route.

5. ESTIMATION OF FUEL SAVING POTENTIALS

It is interesting to note that the reasons previously given for the use of routinely-applied ATC restrictions have more to do with how the ATC system is operated today, given the timeliness and accuracy of the data that is available and the level of ATC automation technology that is currently implemented, than they do with any inherent capacity limitation of airspace itself to hold safely separated aircraft movements.

To the extent that this observation holds true, then it should be possible to design, develop, and implement specific functional improvements to the ATC system which will reduce the need for the fuel-inefficient practices in use today. For example,

1. At flight planning time, expect the airspace user to want to file for the most favorable route and altitude, given his knowledge of weather and winds aloft, aircraft performance, and flight objectives. Reduce ATC's needs for route or altitude constraints which are not the direct result of actual or forecast aircraft movements and severe weather activity. Improve both the ATC system's and the user's ability to learn about and adapt to changes in the winds and temperatures aloft.

2. At flow planning time, reduce the uncertainties that now exist regarding the actual demand for the runway and for other ATC services versus the runway or control capacities expected to be available.

3. At clearance planning time, reduce the uncertainties that now exist with regard to the effects of pilot planned altitude profiles, speed schedules and other relevant variables.

4. At clearance planning time, reduce the workload associated with coordinating acceptable clearances between control jurisdictions.

5. In real time, reduce the controller workload associated with transfer of control procedures, separation monitoring, clearance/instruction formulation, and the delivery of ATC messages to aircraft.

Table 5-1 summarizes five postulated functional improvements which directly satisfy one or more of these objectives. The columns of the table represent the postulated functional improvements ordered in a possible implementation sequence, left to right. The rows of the table represent specific features of the postulated ATC system, based on the Automated En Route ATC

TABLE 5-1

POSTULATED FUNCTIONAL IMPROVEMENTS EXPECTED TO YIELD SIGNIFICANT FUEL BENEFITS

	Improved En Route Metering	Clearance Planning Aids for Controller	Improved Input Data Sources	Computer-Generated Clearance Plans	Computer-Generated ATC Uplink Messages
External Data Inputs					
Winds & Temperatures Aloft	Updated Winds Model	Adaptive Winds Model	Better data sources (e.g., R-T Radar, AMDAR)	-	-
Severe Weather to be Avoided	-	3D Polygons from CWSU	-	-	-
Volumetric Airspace Constraints	-	Static Conflict Boxes	Extended Tentative Scheduling	-	-
Metered Flow Constraints	Updated Acceptance Rates	-	Automated Interfacility Coordination	-	-
Aircraft Climb/Descent Profiles	Adapted by Type for Weight & Temperature	-	Downlinked Altitude Profiles & Airspeeds (opt.)	-	-
Initial Flight Plans	Gross Weight is Filed	Fewer IFR Preferred Routes are needed	Fewer	Fewer Yet	Filed Direct to Arrival Fixes
	Type Aircraft is Exact	-	-	-	-
In-Flight Service Requests	-	-	Downlinked Pilot Requests	Pilot-to-AERA Direct Negotiations	-

TABLE 5-1

(Cont'd)

Planning Functions and Outputs	Improved En Route Metering	Clearance Planning Aids for Controller	Improved Input Data Sources	Computer-Generated Clearance Plans	Computer-Generated ATC Uplink Messages
Modeling of Nominal Profiles & Procedures	Descent Only	All Phases of Flight	Move Accurate given Better Inputs	-	-
Delay Prediction for Absorption Planning	Discounted Delays at Vertices	-	More Accurate given Better Inputs	-	-
Conflict Prediction for Resolution Planning	-	Direct Routes Probe Discounted Real/Possible Conflicts	More Accurate given Better Inputs	-	-
Problems Prediction for Backup Planning	-	(as needed)	-	(as needed)	(as needed)
Displays of Computer-Prepared Planning Info. (updated as needed)	Metering Position Lists Arrival Sector Meter Lists Absorption Strategy Lists	Flight Intent/Status Lists Planned Clearance Directives More Informative PVD Callable Flight Profile Display	?	?	?

TABLE 5-1

(Cont'd)

	Improved En Route Metering	Clearance Planning Aids for Controller	Improved Input Data Sources	Computer-Generated Clearance Plans	Computer-Generated ATC Uplink Messages
Planning Functions and Outputs, Cont'd					
Flow/Metering Controller Tools	Change Acceptance Rates	?	?	?	?
	Change Runways in Use	?			
	Change Airport Delays	?			
Sector Controller Tools	(none as presently specified)	Interactive Clearance Planning incl. Metering	?	for Oversight/Override(?)	-
Modeling of Controller-Planned Clearances (other than FP reroutes)	(none as presently specified)	Clearance Directive Modeling (as needed)			
Validity Checking of Resultant Plans	(none as presently specified)	(as needed)	?	Lots	Lots more
Computer-Planned Clearance Directives	(none as presently specified)	Outbound Handoffs, Procedural Restrictions, Metering Advisories	More Routine CDs	Nearly all CDs, including Backup CDs, also Tools to use Planner as controller aid	-

TABLE 5-1

(Concl'd)

	Improved En Route Metering	Clearance Planning Aids for Controller	Improved Input Data Sources	Computer-Generated Clearance Plans	Computer-Generated ATC Uplink Messages
Real Time Functions and Outputs					
Association/Conformance Checking	-	All Phases of Flight	More Efficient Protection Volumes for Participating Aircraft	-	Out Laterally Warnings Out Vertically Warnings Correction Instructions
Closely-Coupled FP-to-Track Updates	30 sec. CTA Updates, Metered Aircraft	All Controlled Aircraft	Tighten Updates as needed	-	Assigned Speed Corrections
Tactical Execution of Clearance Plan	(no aids as presently specified)	Clearance Directive Prompts to Controller	-	-	ATC Clearances
Safe Passage Monitoring	-	Primary Monitor of Tracked Aircraft Safe Passages	-	-	
Tactical Conflict Resolutions	-	Advisories to Controllers	-	-	Safe Passage Adjustments
VFR Intruder Avoidance	-	Advisories to Controllers	-	-	Safe Passage Adjustments

(AERA) system concept documented in Reference 12. The entries in the table indicate the level of sophistication assumed to be achieved for any row feature and column improvement. A dash indicates no change from the prior improvement level. See Reference 13 for the details of the level of en route metering against which the "improved version" assumed here is derived. See Reference 12, Appendix 5 for a comparison of en route metering methods.

5.1 Estimating the Fuel-Saving Potentials of Specific Functional Improvements to En Route ATC

Table 5-2 summarizes the results of an attempt to estimate the fuel-saving potentials of the specific functional improvements listed in Table 5-1. The quantative estimates are divided into three categories:

- Arrival Delays
- Procedural Route/Altitude Restrictions
- Other ATC Factors (Not examined further)

"Arrival Delays" refers those fuel benefits to be gained by (1) minimizing the mis-match between the rates that arrival aircraft are fed to terminal areas and available runway capacities, and (2) maximizing the fuel-efficiency of the maneuvers used in absorbing landing delays, either while aircraft are en route or prior to departure. It excludes any reduction in arrival delays which might be brought about improving runway capacities, either by pouring more concrete or by improving final sequencing and spacing efficiencies through improved ATC automation in the terminal area.

"Procedural Route/Altitude Restrictions" refers to those restrictions that today are imposed by agreement, habit, or on a statistical worst-case basis, which pilots of aircraft or analyzers of recorded actual aircraft movements would label as unnecessary, based on the threat to safety alone.

In both categories, it is recognized that not all arrival delays or route/altitude restrictions are potentially correctable. Some are in fact needed because of actual aircraft competition in real time for a given runway or volume of airspace. However, the magnitude of these necessary delays and restrictions is not at issue here, and no attempt is made to estimate those magnitudes in terms of the extra fuel burned.

TABLE 5-2

ESTIMATES OF THE FUEL SAVING POTENTIALS OF SPECIFIC FUNCTIONAL IMPROVEMENTS TO EN ROUTE ATC

	Basis for Estimates	Total Estimate Gallons x 10^6 (% of 1981 Fuel Burn[1])	Improved En Route Metering	Clearance Planning Aids for Controller	Improved Input Data Sources	Computer-Generated Clearance Plans	Computer-Generated ATC Uplink Messages
Arrival Delays							
Potentially Correctable		300 (3%)	1.5%	-	1.0%	0.5%	-
Procedural Route/Altitude Restrictions							
Potentially Correctable		300 (3%)	-	1.5%	0.5%	0.5%	0.5%
			1.5%	1.5%	1.5%	1%	0.5%
Other ATC Factors							
Reduce Vertical Separations Above FL290	Note 2	up to 65 (0.6%)	-	-	-	-	-
Lower Ceiling on 250 Knot Speed Limit	Reference 1	20 (0.2%)	-	-	-	-	-
Permit Delayed Flap Approaches	Reference 1	0 to 50 (0.5%)	may help	-	may help	may help	may help
Reduces Delays in Responding to Pilot Requests for Better Routes/Altitudes	Section G-11	not estimated	-	should help	should help	should help	should help

TABLE 5-2

(Cont'd)

Notes

1. In Civil Aviation alone, the forecast 1981 fuel burn is 12 billion gallons, of which 10 billion gallons is air carrier jet fuel. Since the references have predominately dealt with fuel-inefficiencies relative to air carrier turbojet operations, 10 billion gallons is used as the basis value.

2. The 65 million gallon estimate is for all ATA airlines between August 1978 and August 1979 and was provided to the FAA by ATA. It assumes a reduction to 1000 feet for all flight levels above FL290.

   A 10 to 12 million gallon estimate is provided in Reference 1. The 10 million gallon estimate assumes a reduction to 1000 feet only between flight levels 290 and 330. The 12 million gallon estimate assumes a reduction to 1500 feet between FL290 and FL410. The basis for these estimates assumes that traffic competition for the fuel optimum flight level is not a factor, and thus they may be somewhat conservative estimates.

   The recent Oceanic Area System Improvement Study (OASIS), sponsored by the FAA and coordinated by the International Aviation Review Committee, estimated savings, through a system simulation, of over $20 million for the North Atlantic Region traffic alone in 1981, assuming reduction to 1000 feet for all flight levels above FL290.

This estimate is based on a single 2.5 hour observation of Atlanta arrivals during the morning of Thursday, 12 January 1978, as reported in Reference 5. The root causes of the "potentially correctable" delays at Atlanta were judged to be (1) under-utilization of one of the two parallel runways relative to the observed throughput on the other, and (2) excessive and poorly timed metering restrictions. Without more automated tools which would allow Atlanta to treat both runways as truly independent, and to dynamically estimate the timing and aircraft type mix of the arrival sequence at each runway threshold - before the aircraft begin their descent to the runway - it is hard to see how the performance could be made much better than it was. Nonetheless, later analysis determined that 3 out of every 4 minutes of the actual delay were "potentially correctable", assuming the existence of an ideal system for metering and spacing those arrivals, and using a final spacing between aircraft which was equal to the average of the spacings actually observed between aircraft landing on the north runway during the busy hour. One minute out of every 4 was actually needed for spacing these arrivals simply due to an excess in demand over available capacity.

5.1.1 Estimated Savings Related to Arrival Delays

Taking the arrival delays first, Reference 1 provides an analysis which concludes that up to about 600 million gallons could be saved annually if the en route metering and profile descent process could take full advantage of modern technology to (1) ensure that runway utilization is kept closely matched to current runway capacities, and (2) made use of along-course speed reductions in cruise and descent, using vectoring and holding only when necessary, to absorb discounted landing delays. It also concluded that if profile descent procedures were implemented with only rudimentary en route metering procedures (e.g., Ft. Worth and Denver type systems), then that savings would be reduced to something over 300 million gallons annually.

For the purpose of this exercise, it is assumed that the 300 million gallon differential between sophisticated en route metering and rudimentary route en metering as reported by Reference 1 represents 300 million gallons of potential savings due to the combined benefits attributed to all functional improvements in Table 5-2. That 300 million gallons represents a 3% annual saving based on the current annual jet fuel burn of the U.S. civil air fleet alone.

All of the estimated 3% annual fuel savings would not be realized until sometime after all functional improvements have been implemented. Assuming an incremental implementation, the

3% savings was somewhat arbitrarily allocated as 1.5%, 1.0%, and 0.5%, on the theory that the unrealized benefits following each step will become progressively harder to realize.

Note: Improved en route metering is credited with half of the total savings on the assumption that the tentative landing schedule is computed on the basis of actual traffic demand for the runway, and not some guessed at or experienced-based acceptance rate. That is, runway capacity should be dynamically estimated from both the expected departure sequence and the expected arrival sequence for each active runway. This has not been done in the en route metering packages defined so far for implementation.

If this does not become true until later, the fuel benefit of improved en route metering should be reduced considerably (say to 0.5%), since optimizing runway utilization is far more important to fuel savings than is absorbing landing delays in a fuel-efficient manner.

5.1.2 Estimated Savings Related to Procedural Route and Altitude Restrictions

A number of specific cases were analyzed, and it seems apparent that an improved ATC system design could permit significant reductions in the need for rigid route and altitude restrictions. Such restrictions are routinely imposed today in situations where, with better and more timely knowledge of conflict potentials (which are often zero), and with better tools for quick clearance coordination, those restrictions would often be unnecessary.

In particular, it was found that the airway route structure may account for an average 2% penalty nationally, relative to more efficient random routes. In addition, the restrictions imposed within 150 miles or so of the major terminal areas may account for very high penalties on those flights which buck or cross the major flows. On this basis, seems reasonable to assume a 3% potential fuel savings nationally might be possible, if all the functional improvements in Table 5-1 are assumed to be made. The 3% represents an additional 300 million gallons, considering the annual jet fuel burn of the U.S. civil air fleet alone.

This 3% savings is attributed to the combined benefits of all functional improvements. Assuming an incremental implementation, the 3% savings was somewhat arbitrarily allocated as 1.5%, 0.5%, 0.5%, and 0.5%, on the theory that the unrealized benefits following each step will become progressively harder to realize.

Note: "conflict-free clearance planning" is credited with half of the total savings on the assumption that all of the subfunctions listed for it in Table 5-1 are realized. A more modest definition may require shifting some of the savings to later steps.

5.1.3 Other Possible Sources of Fuel Savings thru ATC System Improvements

The second half of Table 5-2 identifies a few other "factors" which might produce fuel savings, given action on either the numbered functional improvements or on other steps the FAA might take. All of these savings are modest compared to the entries in the first half of the table, but are large enough to deserve further consideration. See the cited references for details.

5.2 The Estimated Fuel Benefits Summarized

Table 5-3 summarizes

1. What the postulated functional improvements are upon which the major fuel savings are based,

2. Why the reduction of ATC-imposed fuel inefficiencies is expected, given that each functional improvement is made,

3. How much of an impact each improvement step is estimated to make in terms of a percentage saving of the expected annual fuel burn, and

4. The earliest year in which some measureable benefit might be expected to be seen, given that the first operational implementation of this functional improvement is made in the year "I".

However, the earliest year in which the total savings might be realized cannot be established until more realistic implementation schedules become known.

TABLE 5-3

ROUGH ESTIMATES OF WHEN, HOW, AND WHY FUEL BENEFITS CAN BE ACHIEVED

Thru Postulated Functional Improvements 3, 8, 9, 10, 11

Postulated Functional Improvements	Impact on ATC-Imposed Fuel Inefficiencies	Estimated Total Fuel Savings, Percent of Annual Burn	Earliest Year in which Savings Could Begin	Earliest Year in which Total Savings Might Be Realized
<u>Improved En Route Metering</u>	<u>Reduction in Potentially Correctable Delays</u>:	1.5%	I + 1	?
Adapted Altitude & Speed Profile Data Updated Winds Model Exact Aircraft Types & Gross Weights are Filed Landing Delays Prediction & Discounting Delays & Absorption Advisories to Controllers	More Accurate Calculation of Arrival Times & Natural Landing Sequence Better Coordinated Metering Fix Flows Fuel-Efficient Delay Absorptions Computed, Not Guessed At More Efficient Runway Utilization, Given Competition for the Runway			
<u>Clearance Planning Aids for Controller</u>	<u>Reduction in Procedurally Imposed Restrictions</u>:	1.5%	I + 2	?
4D Modeling of Expected Flight Paths Adaptive Winds Model using Tracked Aircraft Data Procedural & Metering CDs are Computer Generated Direct Routes Probe (Traffic, Severe Weather) Conflicts Prediction & Discounting Conflict Advisories & Clearance Prompts to Controllers Interactive Planning of Clearance Directives Safe Passages Monitoring	Route & Altitude Coordination via Computer Climb/Descent Profile Uncertainties Reduced More Direct Routes Requests Satisfied Fewer Altitude Restrictions Needed Faster Responses to Pilot Requests for Route/Altitudes			

TABLE 5-3

(Cont'd)

Postulated Functional Improvements	Impact on ATC-Imposed Fuel Inefficiencies	Estimated Total Fuel Savings, Percent of Annual Burn	Earliest Year in which Savings Could Begin	Earliest Year in which Total Savings Might Be Realized
<u>Improved Input Data Sources</u>	<u>Further Reductions in Both Delays & Restrictions:</u>	1.5%	I + 1	?
Downlinked Altitude Profiles & Airspeeds (Optional) Winds & Temperature Aloft from Equipped Aircraft Downlinked Pilot Requests for Routes, Altitudes Extended Tentative Scheduling with TRACON Automated Inerfacility Coordination (CFCF, Other ARTCCs) More Computer-Planned Routine CDs	More Accurate Prediction of Climb/Descent Profiles More Accurate Prediction of Expected Arrival Times More Efficient Protection Rules given Greater Accuracies More Efficient Delay Prediction & Absorption Strategies Improved Runway Utilization			
<u>Computer-Generated Clearance Plans</u>	<u>Further Reduction:</u>	1%	I + 2	?
Pilot-to-Computer Direct Negotiations Computer-Stored Strategies for Clearance Directives Planning Controllers Displays for Oversight/ Override & Control Messages to Pilots Routine Messages can be Datalinked Direct Controller is still Pilot's Contact for all Control Instructions	More Consistent & Thorough Clearance Planning Real Time Responses to Pilot Requests for Routes/Altitudes			

TABLE 5-3

(Concl'd)

Postulated Functional Improvements	Impact on ATC-Imposed Fuel Inefficiencies	Estimated Total Fuel Savings, Percent of Annual Burn	Earliest Year in which Savings Could Begin	Earliest Year in which Total Savings Might Be Realized
<u>Computer-Generated ATC Uplink Messages</u>	*Further Reductions:*	0.5%	I + 3	?
Computer-Interpretation of All Clearance Directives	Filed Direct Routes to Arrival Fix Commonplace			
Computer-Issuance of Control Messages in Real Time via Data Link	Procedural Altitude Restrictions Rarely Needed			
"Controller-as-Manager" Displays & Tools	Nearest Thing to Unrestricted Flight Possible			
		6%		

APPENDIX A

A Review of "Operation Free Flight"

"Operation Free Flight - An Operational Evaluation of RNAV Direct Route Flight Plan Filing in Today's National Airspace System" is the title of a report recently published by FAA's Air Traffic Service (Reference 6). The evaluation began 1 June 1980, with data collected through 31 December 1980 included in the published report.* The project was conceived and managed by FAA's En Route Procedures Branch (AAT-330), with Wayne Minnick as Project Manager. Basil Ward (AAT-330) and Dan Creedon (formerly Chief of AAT-330, now Chief of AAT-410) were also instrumental in the project.

The objectives of Operation Free Flight (OFF) were to determine the:

1. Feasibility of filing and flying great circle direct routes in the current ATC system.

2. Potential fuel savings which could be realized relative to flying the traditional airway routes.

3. ATC prohibitions, if any, to clearing such flights as filed.

4. Impacts on the ATC system in terms of changes in controller or computer workload, the ability of the NAS Stage A computer system to accurately post the necessary flight strips, etc.

A.1 Approach

The approach taken was as follows:

1. A acceptable method of filing for RNAV direct routes was found: For the purpose of the evaluation, the following method (illustrated by example) was used to file the proposed route of flight:

IAH LFK 3857/7521 TWIGG KENY2 JFK

Where in this example the:

Departure airport = IAH (Houston, TX)

* The participating airlines continued to file OFF-routes and provide data up until the controller's strike on 3 August, 1981.

Departure transition fix = LFK (Lufkin, TX)

•
•
•

(assumption: pilot will navigate a great circle route between transition fixes)

•
•
•

Arrival transition fix — 3857/7521 TWIGG (intersection near Kenton, DE)

Standard Terminal Arrival (STAR)* = Kennedy-2

Arrival airport = JFK (Kennedy, NY)

and where 3857/7521 = the latitude/longitude coordinates of the intersection TWIGG rounded to the nearest minute.

In a few special cases (e.g., avoiding Edwards AFB and White Sands Restricted Areas), midcourse turnpoints were established to keep the great circle route from penetrating a denied area. In other cases of routes crossing restricted areas, controller coordination to, say, top the unused portion of the area was relied upon. When a filed turnpoint was necessary, it was entered using the same procedure as described for TWIGG above.

Basically, this method solved two problems:

a. The latitude/longitude version of the arrival transition fix assured that the route could be converted by any center's computer, regardless of where the transition fix was located within the U.S. If only the alphanumeric name of the transition fix was filed, all transition fixes used would have to have been included in the adaptation data base of every center's computer.

b. The name of the transition fix was also filed to make an otherwise unrecognizable latitude/longitude location recognizable by controllers for control and voice communication purposes.

* Because of the regulatory implications of the term "route", it was recently dropped from the definition of a "STAR".

There are some additional technical problems which are discussed in a later section. Suffice it to say here that this method worked well enough for the purposes of the evaluation.

To quote the report, "The first group of city pairs were linked to Atlanta (Hartsfield) and Miami International and only a few fights per day were selected to participate. Each flight was carefully monitored by ARTCC supervisory personnel until it was determined that [certain previously mentioned] concerns did not appear to be limiting factors."

2. Airport pairs and flights eligible for participation were selected, with the cooperation of the voluntarily participating airlines (Eastern, Pan Am, United and National*). The number of airport pairs were expanded from an initial 12 pairs involving departures from Atlanta and Miami (in June, 1980) to 27 pairs (in August 1980). The expanded network tested "routes flown in all directions" over the U.S. and increased the number of flights daily that could participate. Tables A-1 thru A-3 list the 27 airport pairs, the number of flights that had OFF-route flight plans filed for them during the period June - December 1980, and the percentage that number represents of the flights that were eligible for participation during the reporting period.

To be eligible for participation, each aircraft scheduled to make each flight had to carry the requisite RNAV equipment for flying great circle routes. Some routes established for the evaluation ended up with no eligible participants because of equipment changes; e.g., substitution by the carrier of a non-RNAV equipped B727 for an L1011 with RNAV.

To actually participate, each flight had to have an OFF-route flight plan filed for it. Whether an OFF-route was filed for any particular flight was determined by the airline's preflight planning computer. Quoting from the reference, "Eastern Airlines provided this service to both the former National Airlines and to Pan American. Multiple routes of flight between all cities are stored in the United and Eastern computers." The airlines that participated in Operation Free Flight shared the same basic objective in selecting daily flight plan routes: "minimize fuel consumption".

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* Since National merged with Pam Am after the project began, all data provided by National was added to the Pan Am data.

TABLE A-1

OFF-ROUTES FOR EASTERN U.S. DEPARTURES, BY AIRPORT

	Flights Filing OFF-Route Flight Plans (% of Flights Eligible)			
	Eastern	Pan Am	United	Total
Kennedy to:				
Houston	20 (34%)	31 (34%)	0	51 (34%)
San Francisco	13 (12%)	0	21 (25%)	34 (17%)
Los Angeles	11 (9%)	0	25 (9%)	36 (9%)
Newark to:				
Chicago	0	0	12 (52%)	12 (52%)
San Francisco	0	0	51 (60%)	51 (60%)
Philadelphia to:				
Chicago	-	-	-	-
Pittsburg to:				
Atlanta	4 (7%)	0	0	4 (7%)
Buffalo to:				
Atlanta	0^2 (0%)	0	0	0^2 (0%)

TABLE A-1

(Cont'd)

Atlanta to:	Flights Filing OFF-Route Flight Plans (% of Flights Eligible) Eastern	Pan Am	United	Total
Charlotte	-	-	-	-
Pittsburg	57 (27%)	0	0	57 (27%)
Newark	-	-	-	-
Buffalo	197 (46%)	0	0	197 (46%)
Chicago	14 (74%)	0	0	14 (74%)
Los Angeles	160 (65%)	0	0	160 (65%)
San Francisco	22 (61%)	0	0	22 (61%)
Seattle	78 (43%)	0	0	78 (43%)
Miami	-	-	-	-
Charlotte to:				
LaGuardia	65 (74%)	0	0	65 (74%)
Miami to:				
Chicago	130 (61%)	0	0	130 (61%)
Los Angeles	0	302 (36%)	0	302 (36%)
San Francisco	97 (46%)	280 (46%)	0	377 (46%)
	868	613	109	1590

---

1. How to read this table: From Kennedy to Houston, 34% of the eligible participating flights actually had OFF-route flight plans filed for them in both the Eastern and Pan Am cases: 20 and 31 flights respectively. Dashes indicate that no carrier had eligible participants during the data collection period ending 12 December 1981.* A zero without percentage eligible in parenthesis indicates that a particular carrier had no eligible participants. Zeros with (0%) shown indicates that the carrier indicated had eligible participants, but none had OFF-routes filed for them.

*For example, the only carrier might change equipment planned for the route from a wide-body aircraft with RNAV to a B727 without.

Source: Derived from Table 6-2, Operation Free Flight, FAA-AT-81-1, July 1981.

2. The normal airway route length was within 4 miles of the OFF-route length, so the former route was always picked by Eastern's pre-flight planning computer.

TABLE A-2

OFF-ROUTES FOR CENTRAL U.S. DEPARTURES, BY AIRPORT

	Flights Filing OFF-Route Flight Plans (% of Flights Eligible)			
Chicago to:	**Eastern**	**Pan Am**	**United**	**Total**
Philadephia	-	-	-	-
Newark	0	0	20 (41%)	20 (41%)
Miami	18 (30%)	0	0	18 (30%)
Los Angeles	0	0	13 (15%)	13 (18%)
Hoston to:				
Kennedy	34 (57%)	52 (57%)	0	86 (57%)
San Francisco	-	-	-	-
	52	52	33	137

1. How to read this table: See Footnote 1 on Table A-1.

TABLE A-3

OFF-ROUTES FOR WESTERN U.S. DEPARTURES, BY AIRPORT

	Flights Filing OFF-Route Flight Plans (% of Flights Eligible)			
Seattle to:	Eastern	Pan Am	United	Total
Los Angeles	-	-	-	-
Atlanta	3 (8%)	0	0	3 (8%)
San Francisco to:				
Houston	-	-	-	-
Atlanta	-	-	-	-
Miami	-	-	-	-
Newark	-	-	-	-
Kennedy	14 (12%)	0	30 (37%)	44 (22%)
Los Angeles to:				
Chicago	0	0	45 (54%)	45 (54%)
Atlanta	0[2] (0%)	0	0	0[2] (0%)
Miami	0	33 (36%)	0	33 (36%)
Seattle	-	-	-	-
Kennedy	0[2] (0%)	0	67 (24%)	67 (24%)
	17	33	142	192
Eastern + Central + Western Departures	937 (36%)	698 (40%)	284 (27%)	1919 (36%)

1. How to read this table: See footnote on Table A-1.

2. The normal "great circle" route used by Eastern was slightly shorter than the defined OFF-route, so the latter was never selected by Eastern's pre-flight planning computer.

"Operation Free Flight routes were subjected to the same computer analysis as all others. If the computer selected the OFF-route, it was filed with ATC; if not selected, the flight was not considered to be a participant."

For identification, the flight plans of participating flights were filed with the statement "Operation Free Flight" under remarks.

3. Great-circle routes were implicitly understood to exist between transition fixes: It was understood that the pilot of a flight so filed can and will navigate a great circle direct route between the filed transition or turnpoint fixes using his on-board RNAV equipment.

4. Needed ATC constraints were negotiated: Because of the procedural route/altitude restrictions already established by ATC within some radius of the departure and arrival terminals, great circle flight was not possible from airport to airport. Rather, standard traffic flows were followed between established transition fixes and their associated airports, both at the departure end and the arrival end of each OFF-route.

The Air Traffic Division of the Southern Region (ASO-500) coordinated the needed constraints and other procedural aspects of the evaluation with the FAA regions and en route centers affected.

Tables A-4 thru A-6 list for each airport the transition paths that resulted for departures and arrivals, the direct route distances between the airport and its associated transition fixes, the destination airports associated with each departure transition fix, and the originating airports associated with each arrival transition fix.

For certain routes, an additional turn point had to be established. See footnotes to Tables A-4 through A-6.

5. Radar separation was required for operation on OFF-routes: Three types of RNAV avionics were used during the evaluation:

Eastern L1011s and A300s: OMEGA (Litton LTN-211, Mark 2)

United B747s and DC10s: INS (Delco Carousel)

Pan Am/National B747s and DC10s: VOR/DME Referenced (Collins AINS-70 RNAV)

TABLE A-4

TRANSITION PATHS FOR EASTERN U.S. TERMINALS

	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
1. Kennedy, NY		
Departures		
Robbinsville (RBV)..FLYPI	105	Houston, San Francisco
Robbinsville (RBV)..BOGGE	235	Los Angeles
Arrivals		
HOXIE..Sparta (SAX)..ELLIS	200	Los Angeles, San Francisco,
TWIGG. Kennedy-2	135	Houston
2. LaGuardia, NY		
Departures		
Arrivals		
Newcastle (EWT).Proud-1	110	Charlotte
Woodstown (OOD).Proud-1	100	Charlotte

1. "Direct Route Distance" as measured between the airport and the transition fix indicated, point-to-point on a map; does not account for terminal area vectoring.

Also note the following conventions:

Name (XYZ) = A named VOR/DME with its 3 letter abbreviation
NAAME = The 5 letter designator for a named radial/route intersection
Name - Number = A Standard Terminal Arrival (STAR)

For a departure, the transition fix is the last fix named; for an arrival, the transition fix is the first fix named.

Source: Derived from Appendix C, Operation Free Flight, FAA-AT-81-1, July 1981.

TABLE A-4

(Cont'd)

	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
3. Newark, N.J.		
Departures		
Solberg (SBJ)..East Texas (ETX)	100	San Francisco, Chicago
Arrivals		
Newcastle (EWT).Harry-1	100	Atlanta
Slate Run (SLT).Slate-1	200	San Francisco, Chicago
Average for NY Metro Area = 145 miles		
Departure Average = 147 miles		
Arrival Average = 141 miles		
4. Philadelphia, PA		
Departures		
Pottstown (PTW)..FLOAT	45	Chicago
Arrivals		
Harrisburg (HAR).V210.BUCKS	85	Chicago

TABLE A-4

(Cont'd)

	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
5. Pittsburg, PA		
Departures		
BURGS	50	Atlanta
HACKS	95	Atlanta
Departure Average =	72	
Arrivals		
Bellaire (AIR)	45	Atlanta
6. Buffalo, NY		
Departures		
Jamestown (JHW)	50	Atlanta
Arrivals		
Dunkirk (DKK)	40	Atlanta

TABLE A-4

(Cont'd)

	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
7. Atlanta, GA		
Departures		
Spartanburg (SPA)	150	Newark
Athens (AHN)	70	Charlotte
Vulcan (VUZ)	125	San Francisco, Los Angeles
Chattanooga (CHA)	90	Seattle
Hinch Mountain (HCH)	150	Chicago
Knoxville (TYS)	140	Pittsburg, Buffalo
direct	-	Miami
Departure Average =	121	
Arrival Average =	190	
Arrivals		
Toccoa (TOC).Macey-2	85	Pittsburg, Buffalo
Memphis (MEM).Rome-1	295	Seattle, Los Angeles, San Francisco
8. Charlotte, NC		
Departures		
(no transition fix specified)	-	LaGuardia
Arrivals		
Lockhart, SC (2QH)	25	Atlanta

TABLE A-4

(Concl'd)

9. Miami, FL	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
Departures		
Orlando (ORL)	185	Chicago
Sarasota (SRQ)	175	Los Angeles, San Francisco via NEPTA[2],
Arrivals		
LEILA.LEILA-2	90	Chicago, Miami
Sarasota (SRQ).LEILA-2	165	Los Angeles via NEPTA[2], San Francisco via NEPTA[2]

2. NEPTA was a waypoint needed to keep the flight south of the offshore Warning Areas serving NAS Pensacola, Eglin AFB, and Tyndal AFB.

TABLE A-5

TRANSITION PATHS FOR CENTRAL U.S. TERMINALS

1. Chicago, IL	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
Departures		
Keeler (ELX)	80	Newark
WHETT	75	Philadelphia
COVIE	110	Miami
Iowa City (IOW)	170	Los Angeles
Departure Average =	109	
Arrivals		
Boiler (BVT)..Chicago Heights (CGT)..BEBEE	100	Atlanta, Miami
Fort Wayne (FWA).FWA311..CGT097. CGT..BEBEE	130	Philadelphia, Newark
Bradford (BDF)..VAINS	90	Los Angeles
Arrival Average	107	

1. "Direct Route Distance" as measured between point-to-point on a map; does not account for terminal area vectoring.

Also note the following conventions:

Name (XYZ) = A named VOR/DME with its 3 letter abbreviation
NAAME = The 5 letter designator for a named radial/route intersection
Name - Number = A Standard Terminal Arrival Route (STAR)

For a departure, the transition fix is the last fix named; for an arrival, the transition fix is the first fix named.

Source: Derived from Appendix C, Operation Free Flight, FAA-AT-81-1, July 1981.

TABLE A-5

(Cont'd)

2. Houston, TX	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
Departures		
Lufkin (LFK)	80	Kennedy
Junction (JCT)	235	San Francisco
Departure Average =	158	
Arrivals		
Daisetta (DAS)	40	Kennedy,
College Station (CLL)	70	San Francisco via CEARA[2]
Arrival Average =	55	

2. CEARA was a turnpoint needed to route the flight to the north of the restricted areas serving White Sands Proving Ground and Holloman AFB.

TABLE A-6

TRANSITION PATHS FOR WESTERN U.S. TERMINALS

1. Seattle, WA	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
Departures		
RADDY	40	Atlanta
WIRTT	25	Los Angeles
	Departure Averge = 32	
	Arrival Average = 75	
Arrivals		
Moses Lake (MWH)	125	Atlanta
WIRTT	25	Los Angeles

1. "Direct Route Distance" as measured between point-to-point on a map; does not account for terminal area vectoring.

Also note the following conventions:

Name (XYZ) = A named VOR/DME with its 3 letter abbreviation
NAAME = The 5 letter designator for a named radial/route intersection
Name - Number = A Standard Terminal Arrival Route (STAR)

For a departure, the transition fix is the last fix named; for an arrival, the transition fix is the first fix named.

Source: Derived from Appendix C, Operation Free Flight, FAA-AT-81-1, July 1981.

TABLE A-6

(Cont'd)

2. San Francisco, CA	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
Departures		
Linden (LIN)..Mina (MVA)	205	Houston, Miami, Atlanta, Kennedy, Newark
Arrivals		
Modesto (MOD).Modesto-3	65	Kennedy via CYS[2], Newark via CYS[2]
Coaldale (OAL).Modesto-3	215	Houston, Kennedy via CYS[2], Newark via CYS[2]
Wilson Creek (ILC)..Coaldale (OAL).Modesto-3	375	Atlanta
Boulder City (BLD)..Modesto (MOD).Modesto-3	365	Atlanta, Miami
Arrival Average =	255	

2. Cheyenne, WY (CYS) was a turnpoint thought by the Denver center to be needed en route in order to avoid disrupting en route metering operations to Denver's Stapleton airport.

TABLE A-6

(Cont'd)

3. Los Angeles, CA	Direct Route Distance[1] (Nearest 5 Miles)	For Flights To/From:
Departures		
Daggett (DAG)	110	Chicago via LAS[3], Kennedy
Thermal (TRM)	115	Atlanta
Thermal (TRM)..Blythe (BLH)	185	Miami via EWM[1],
Thermal (TRM)..Parker (PKE)	195	Miami via EWM[1],
Santa Barbara (SBA)..Salines (SNS)	230	Seattle
Bakersfield (BFL)	100	Seattle
Departure Average =	156	
Arrivals		
Twenty-Nine Palmes (TNP).Downe-1	130	Atlanta, Miami via EWM[4],
Avenal (AVE).Moorepark-4	140	Seattle,
Boulder City (BLD)..Hector (HEC).Downe-1	224	Kennedy, Chicago
Arrival Average =	160	

5. Las Vegas, NV (LAS) was a waypoint needed to keep flight south of the restricted areas serving Edwards AFB and NWC China Lake.

4. Newman, TX (EWM) was a turnpoint needed to route the flight south of the restricted areas serving White Sands Proving Ground and Holloman AFB NM.

Because of its ease of application, radar separation was made a prerequisite for flying OFF-routes. That is, the dependence of protected route widths on the type of RNAV set and the aircraft's location relative to its reference (in the VOR/DME case) were avoided as issues. It also relieved the operators of participating aircraft from meeting the terms of FAA Advisory circular 90-45A. This circular covers the certification requirements for aircraft flying published RNAV routes.

6. Pilot/company and ARTCC questionnaires were developed: Post-flight data was gathered by questionnaires filed out by both pilots and ARTCCs. The pilot/company questionnaire asked questions about whether the flight:

a. Was originally cleared as filed? If not, why not?

b. If originally cleared as filed, was it subsequently rerouted via the VOR/DME system? Why? How far from the destination?

c. How advantageous was the use of RNAV?

d. How much fuel did the pilot believe was saved by using the OFF-route?

The company was also asked to estimate the fuel consumption for two assumed cases:

e. Direct routing via the OFF-route

f. Normal airway routing for the flight.

The ARTCC questionnaire asked questions about whether each flight handled with a filed OFF-route flight plan:

a. Was rerouted? Where? Why?

b. Produced an impact on operations? What kind?

A.2 Some Results of Interest Found by the Evaluation Team

The following results are paraphrased or quoted from the reference:

1. Between terminal area transition fixes, great-circle directs were accommodated by the current ATC system: "Participants were very successful in being able to conduct their flights via the

RNAV great circle routes between departure and arrival area fixes", including any filed turn points. The statistics given are:

Percent of Participating Flights	% of Distance between Transition Fixes Flown RNAV Direct as Filed
80%	100%
88%	>90%
94%	>80%

"No valid ATC system prohibitions were noted." However, some resolvable problems were cited. For example, arrival transition fixes had to be adjusted to resolve incompatibilities discovered with established arrival flows.

2. Incompatibility with "traffic arrival flow" was a major reason for reroutes: Controllers frequently, but unintentionally, contributed to system problems by reclearing flights direct to the destination airport without regard to the previously negotiated arrival transition fixes. In every case identified, this accommodation caused problems later."

According to the reference, "In nearly all cases the causitive factor was, ironically, traced to 'controller accommodation' of two distinct types."

1. "A participant would require vectoring off the initial direct route ... Later, when the pilot was able to resume normal navigation, the controller would reclear the aircraft [direct] to the destination airport, without regard to the arrival area fix."

2. " ... a controller would become aware that a special use area was not active and ... would reclear the aircraft [direct] to an arrival area fix or destination airport, irrespective of any intermediate fixes which had been filed."

In either case, the aircraft was recleared via a path which did not connect with any of the established arrival routes for the destination airport. According to the reference, "consequently the arrival area ARTCC would instruct the adjacent ARTCC to reroute the aircraft. When this occurred, the coordination between ARTCCs was invariably conducted with respect to the controller recognizable, VOR airway structure and resulted in a reroute via the VOR system for the flight." In such cases, the pilot ended up flying less of a direct route than was otherwise possible.

3. Pilots thought that flying RNAV was advantageous for reasons not necessarily related to fuel savings: According to the reference, about half of the pilots reported that RNAV was "extremely advantageous", another third thought it "very advantageous", and only 1% thought it "not at all advantageous". The reference makes the following comments:

a. Several United pilots "did not consider their INS systems as RNAV systems" and several said "This program is not new. We frequently ask for INS direct to destination after reaching cruise altitude [emphasis is the reviewer's] - and get it."

b. Several pilots who "... were severely limited in the opportunity to primarily navigate with their RNAV equipment, ... still expressed a very positive altitude toward RNAV."

c. "The data ... seem to strongly indicate no correlation between the pilot's altitude toward RNAV" and the fuel saving actually achieved. 75% of the pilots who said they actually achieved less than a 1% fuel savings ranked the utility of RNAV as very or extremely advantageous.

4. Some fuel-savings can be achieved using great-circle direct routes, when such routes are appropriate: Though many of the questionnaires returned by the airlines failed to answer the questions regarding fuel consumption via the normal airway (i.e., the airway route that would have been filed if the OFF-route had not) versus consumption via the great-circle direct route, enough data was supplied to suggest to the authors of Reference 6 that a 2% saving on the average could be realized.* To quote from the report, "Between city pairs, [reported] fuel savings ranged from 0.8% to 4.9% of estimated airway consumption. In gallons, the mean fuel savings range was from 84 gallons to 287 gallons per flight." "Documented fuel savings from Operation Free Flight participants amount to 2.03% of the estimated fuel consumption via airways. Under an expanded program, ... the projected fuel savings for commerical aviation over a 12-month period is 40,000,000+ gallons ... "

---

* Based on feedback received by the evaluation team since the report was published, this result is backed up by airline experience (Per a conservation between the project manager and this writer.)

This, of course, must be qualified to say that when a great-circle route was picked to be the most fuel-conservative route, then flying that route rather than some existing airway approximation to it was found to achieve an average 2% saving, at least by those reporting such data.

5. The route selected by the airlines preflight planning computer is not always the most fuel efficient: According to the reference, "21.4% of all flights that flew 100% of the distance direct, as filed, achieved less than 1% of their fuel savings potential [i.e., what they expected to save relative to the next best airway route]. Weather and upper winds were frequently cited by pilots as reasons for not achieving their potential."

This suggests that better winds and weather aloft data for flight planning purposes might also be necessary to improve the airline route selection process.

A.3 Results of an Independent Analysis of the Reported Data

Subsequent analysis by this reviewer of the June-thru-December data, from the viewpoint of what the current ATC system will/won't allow the airspace user to do to minimize fuel consumption, prompts the following observations:

1. User interest in filing OFF-routes was mixed:

   a. Airport pairs with OFF-routes defined: 39

   b. Airport pairs with OFF-routes and with flights eligible for participation: 27*

   c. Number of eligible flights: 5,356

   d. Number of eligible flights which had OFF-route flight plans filed for them: 1,919 (36%). Of these flights, the break-down by company was:

	Eligible	Participating
Eastern	2574 (48%)	937 (36% of 2574)
Pan Am	1726 (32%)	698 (40% of 1726)
United	1056 (20%)	284 (27% of 1056)
	5356 (100%)	1919 (36% of 5356)

* Some planned usages failed to materialize due to aircraft equipment changes or other factors.

The report notes that some great-circle routes, or airway routes which were almost great circle, were already defined in Eastern's preflight planning computer for these airport pairs: LAX-ATL, LAX-JFK, and BUF-ATL. When a great circle route was chosen for one of these airport pairs, it was always one of prior routes, rather than the later defined OFF-route. If the question is: "How often was a great circle route filed for one of the eligible flights?", the number 1,919 (36% of those eligible) is low by (at least) this amount. To estimate how low, assume that 40% of those eligible actually filed for great circle routes:

<u>Eastern</u>

LAX-ATL	72 x 0.4	=	29
LAX-JFK	119 x 0.4	=	48
BUF-ATL	120 x 0.4	=	48
			125

This would bring the total of great circle routes, however defined, and the percentage participation figures by company to:

Eastern	937 + 125	=	1062 (41%)
Pan Am			698 (40%)
United			284 (27%)
			2044 (38%)

2. <u>The most fuel-efficient route is often not a great-circle direct:</u> A number of eligible flights that had other than OFF-routes filed for them: 5,356 - 1,919 = 3,437 (64%). Adjusting for the Eastern flights mentioned above, the number that had other than great circle routes filed for them is:

Eastern	2574	-	1062	=	1512 (59%)
Pan Am	1726	-	698	=	1028 (60%)
United	1056	-	284	=	772 (73%)
	5356				3312 (62%)

That is, about 2/3 of the time, a route other than a great circle was selected by the pre-flight planning computer.* According to the report, the pre-flight planning computer for these airlines is programmed to select the flight plan route/altitude that minimizes fuel consumption. One can only conclude that the most fuel-efficient route for turbojet aircraft is often not a

* Assuming that the only anamolies in the data that need to be accounted for are the three cases cited for Eastern.

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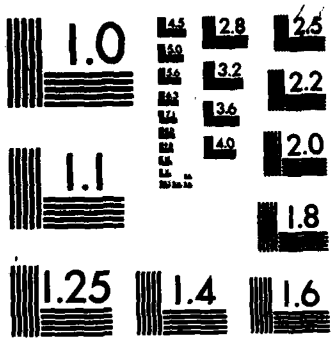

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

The report notes that some great-circle routes, or airway routes which were almost great circle, were already defined in Eastern's preflight planning computer for these airport pairs: LAX-ATL, LAX-JFK, and BUF-ATL. When a great circle route was chosen for one of these airport pairs, it was always one of prior routes, rather than the later defined OFF-route. If the question is: "How often was a great circle route filed for one of the eligible flights?", the number 1,919 (36% of those eligible) is low by (at least) this amount. To estimate how low, assume that 40% of those eligible actually filed for great circle routes:

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	5356				3312 (62%)

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* Assuming that the only anamolies in the data that need to be accounted for are the three cases cited for Eastern.

great-circle direct route. The obvious inference is that forecast winds aloft often make other, less direct, routes look preferable at flight planning time. Unfortunately, no data was provided in the report on what routes were chosen when great-circle directs were not, nor on how much they were displaced laterally from the alternative great circle route, nor on how closely the airway routes filed in those cases match the desired route, given the winds aloft forecast.

3. The user does not have his choice of routes with 150 miles or so of major terminal areas: Referring to Tables A-4 thru A-6, it is seen that an ATC-established route was required in all cases, and that the mileage involved, exclusive of any vectors for spacing, can be significant. The average path distances, to the nearest 5 miles, for the various airport areas are:

	ATC-Established	
	Departure Paths	Arrival Paths
San Francisco (L)	205 n.m.	255 n.m.
Miami (L)	180	128
Los Angeles (L)	156	160
New York (L)	147	141
Atlanta (L)	121	190
Chicago (L)	109	107
Houston (L)	158	55
Pittsburg (L)	72	45
Buffalo M)	50	40
Philadelphia (L)	45	85
Seattle (L)	32	75
Charlotte (M)	-	25

Where by CAB definition (in terms of passenger emplanements):

L = Large hub
M = Medium hub
S = Small hub

The explanation is that: ATC determines what the flight path is between the departure airport and the departure transition fix, and also what it is between the arrival transition fix and the arrival airport. It does it in one of two ways:

a. Published ATC-preferred routes: specifically SIDs, STARs, and Preferred IFR Routes. Airspace users are encouraged to use the applicable published routes when planning and filing their flights.

b. Computer-applied routes: Most published SIDs and STARs are adapted to the computers in the appropriate ARTCCs. Applicable sections of Preferred IFR Routes and arrival and departure routes other than published SIDs and STARs may also be adapted as PDRs, PARs, or PDARs. According to the Pilot/Controller Glossary (in Reference 10):

PDR = "A specific departure route from an airport or terminal area to an en route point where there is no further need for flow control."

PAR = "A specific arrival route from an appropriate en route point to an airport or terminal area."

PDAR = "A route between two terminals which are within or immediately adjacent to one ARTCC's area."

A supervisory message entered into each center's computer controls which adapted routes (SIDs, STARs, PARs, PDRs, PDARs) are active at any given time for a given airport. See Table A-7.

Whenever a flight plan enters a given center's computer for route conversion, it is first tested to determine whether the filed departure airport or the filed arrival airport or both are adapted as "internal" (i.e., within or near this center's boundary) and, if so, whether the pilot filed a currently active SID or STAR, or whether an adapted preferential route applies. Basically, the computer is looking for a transition fix associated with the departure (or arrival) airport which connects the filed route of flight with an active adapted departure (or arrival) route for that airport. If it finds that the filed SID or STAR matches a currently active SID or STAR, that SID or STAR is accepted for route conversion.

If no active SID or STAR applies, then the computer will look for an applicable PDR, PAR, or PDAR. If it finds one, the route as filed is automatically amended to include that preferential route and the initial flight strips are printed accordingly. Specifically, the route as filed is printed in black and the preferential route is printed in red, alerting the controller to clear the flight via the preferential route.

From this discussion, it should be clear that those adapted arrival and departure routes which are currently active in a given center's computer are the routes that will be used to clear aircraft between transition fixes and their associated airports.

TABLE A-7

ARRIVAL/DEPARTURE ROUTES ADAPTED TO CENTER COMPUTERS

	Number of Adapted Routes per Center, 1981										Average Per Center
	BOS	NYC	ATL	CHI	MIA	CLE	DEN	MSP	MEM	OAK	
User-Filed ATC Procedures:											
Standard Instrument Departures (SIDs)	26	72	4	1	2	10	19	13	18	92	See Next
Standard Terminal Arrivals (STARs)	3	10	4	1	5	3	6	0	4	16	Page
ATC-Imposed Routings (when active):											
Preferential Departure Routes (PDRs)	121	116	144	114	85	168	214	146	208	264	
Preferential Arrival Routes (PARs)	179	129	132	115	105	155	293	135	215	245	
Preferential Departure/Arrival Routes (PDARs)	73	171	135	59	98	86	90	40	40	281	
	373	416	411	288	288	409	597	321	463	790	

Source: Unpublished adaptation data statistics from 20 centers, ARD-140, December 1981.

TABLE A-7

(Continued)

	Number of Adapted Routes per Center, 1981										Average Per Center
	SEA	SLC	DCA	IND	JAX	HOU	FTW	ABQ	MKC	LAX	
User-Filed ATC Procedures:											
Standard Instrument Departures (SIDs)	20	8	12	8	28	18	17	26	22	62	24
Standard Terminal Arrivals (STARs)	3	0	0	1	5	8	4	3	2	4	4
ATC-Imposed Routings (when active):											
Preferential Departure Routes (PDRs)	60	68	153	152	37	273	156	120	244	267	156
Preferential Arrival Routes (PARs)	88	90	206	170	59	200	67	175	265	273	165
Preferential Departure/Arrival Routes (PDARs)	24 / 172	24 / 182	139 / 498	80 / 402	11 / 107	160 / 633	129 / 355	73 / 368	60 / 569	180 / 720	98 / 419

Source: Unpublished adaptation data statistics from 20 centers, ARD-140, December 1981.

4. The ATC-preferred routes often add extra flying miles, since often they do not lie on the most direct route between airports. Perusal of the transition paths for both departures and arrivals in Tables A-4 thru A-6 shows that generally a single transition fix serves a sizable airspace quadrant. That is, for any hub area, all departures are typically routed out over one of 4 possible departure transition paths, and all arrivals are typically routed into the hub area via one of 4 possible arrival transition paths. Due the current practice of dedicating segregated arrival routes to each of the 3 major airports in the New York metro area (see Appendix G), there are only 3 possible arrival route and 3 possible departure routes for each airport. See Table G-3 and Figures G-5, G-6, and G-7.

Since there are many points on the compass from which arrivals may come, or departures may go, airport-to-airport direct, it is apparent that only 3 or 4 routes connecting a terminal to a set of transition fixes will force some users to fly longer-than-direct transition paths. For example, in Table A-4 it shows that:

Kennedy arrivals from both San Francisco and Los Angeles had to file via HOXIE...Sparta (SAX)...ELLIS.

Kennedy arrivals from Houston had to file via TWIGG.Kennedy-2.

Referring to Table G-3 and Figure G-2, it is easy to see why. There are only two gateways into Kennedy from airports west of New York:

From:	Gateway to Kennedy:
SW thru NW	HOXIE..SAX..ELLIS
SW thru NE	ENO or TWIGG..ACY...SATES

Regardless where a departure airport to the west of Kennedy is located, the flight will be cleared via one of these two routes to arrive Kennedy. Similar situations can be described for Newark, LaGuardia, and the remainder of at least the large and medium hubs in the U.S.

The net result is that ATC-preferred routes often add extra miles of flying distance, relative to the most direct airport-to-airport routing.

5. Functional limitations in NAS Stage A Model 3 software had to be worked around: The following technical problems were encountered and solved for the purposes of the evaluation:

a. Named transition fixes are not universally adapted: Named fixes beyond 200 miles or so of a given center's boundary are not normally adapted to that center's computer. For flights filing airways or direct routes between VORs, this adaptation practice is sufficient. However, assume a transcontinental flight files from a departure transition fix direct to an arrival transition fix which is more than one center away. That arrival transition fix will not be known by name to the departure center's computer.

Consequently, the flight plan filing method used in the evaluation required the airline to file the latitude/longitude coordinates of the arrival transition fix just ahead of its name in the route field. This was done so that the route could be properly converted by each center's computer along the route of flight.*

b. Direct route segments of zero length are not accepted for route conversion: In the current route conversion process, two successive fixes in the route field of a filed flight plan are treated as a direct route segment. If the filed latitude/longitude coordinate is exactly equal to the adapted latitude/longitude coordinate for the named arrival transition fix in the arrival center's computer, that filed route will be rejected with a "no connect" error by the conversion logic.

For the purposes of the evaluation, it was discovered that all transition fixes used happen to be adapted with non-zero seconds. Therefore, it was sufficient to instruct the carriers to file latitude/longitude coordinates rounded to the nearest minute in order to avoid getting "no connect" rejections.

c. Significant lateral deviation errors can arise, given the way that direct route centerlines are computed, using a flat

---

* The latitude/longitude to stereographic plane (x, y) conversion algorithm in NAS Stage A Model 3 will properly convert any latitude/longitude coordinate pair so long as the latitude is "North" and the longitude is "West".

earth (stereographic) coordinate system. Specifically, the internal representation of the filed direct route created by each center's computer is based on a straight line drawn in that center's stereographic coordinate plane. Depending upon where the stereographic plane's point of tangency is relative to the great circle route, there can be significant lateral displacement between (1) a straight line drawn between two points on the earth's sphere which is then projected into the stereographic plane (i.e., a projected great circle), and (2) a straight line drawn in the plane between those same two points after they have been projected into the plane (i.e., a straight line drawn between two projected points).*

Since each center's computer constructs only that portion of the great circle route which lies near or within its boundaries, and since the point of tangency lies near the middle of the center's airspace**, the errors between the converted flight plan route and the flight's actual track are bounded. The question is: Are they bounded enough to avoid problems? Examples:

- Would flight plans always be forwarded to the right center?
- Would flight strips always be posted to the right sector?
- Are there cases where automatic association checking between the flight plan route and the flight's tracked position is disrupted? How often would such flights go from FLAT to FREE tracking?

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* The current system software does provide optional stereographic-to-gnomonic and gnomonic-to-stereographic conversion routines for computing great circle intersections with control boundaries and other features. However, it is the author's understanding that these routines are used only by those ARTCCs which handle oceanic flights: New York, Miami, Houston, Oakland, and Seattle.

**Theoretically, the point of tangency should be that point on the earth's surface whose distance to the furtherest radar site serving that center is a minimum. Any other point will result in a longer distance to at least one of the radars. Another way of saying this is: The center of the smallest circle which encloses all radar sites serving the center should be the tangency point.

- How often would controllers have to correct the stored flight plan route to match that route with the observed track's path? (Correction might be done using a tracked velocity projection and a trackball reroute action to match the displayed velocity vector.)

Table A-8 tabulates the maximum lateral error to be expected when a great circle route to be flown between filed endpoints A and B is approximated by "drawing" a straight line between A' and B', the latter being the projections of A and B into the stereographic plane for a given ARTCC's computer coordinate system. Below the dotted line are those errors which can exceed 4 miles laterally. See Appendix H for analysis details.

The fact that ATC facilities during the evaluation did not report having significant difficulties in this regard may be attributable to the fact that few of the OFF-routes involved unbroken great circle route segments longer than 1500 n. miles. Tables A-9, A-10, and A-11 show that the longest great circle segment flown was 1830 miles (LAX to JFK), while the average great circle segment flown was:

1000 miles, averaged across all OFF-routes
1130 miles, weighted by all flights using each OFF-route

No data collection procedures other than the facility questionnaire (filed out by supervisors) were used, so it is probably not known whether controllers occasionally had problems or not. All that one can conclude from the published questionnaire results alone is that any problems detected were not significant enough to be made an issue during the evaluation.

6. <u>The stereographic projection system may not be the best coordinate system for internally representing great circle routes:</u> The values tabulated in Table A-8 suggest that the present system design, which relies on stereographic projections for all internal flight and track data representations on the surface of the earth, may not be not the best one to support wide-spread filing of random great circle routes. However, it can be made to work if, say, intermediate waypoints are used to keep the length of great circle segments below 1500 n. miles or so. In concept, such intermediate waypoints could either be (1) filed procedurally by the airspace user, or (2) inserted automatically by the program as needed, <u>if</u> a great circle segment can be unambiguously identified by the <u>filed</u> route parsing algorithm.

TABLE A-8

MAXIMUM LATERAL ERROR IN A STEREOGRAPHIC APPROXIMATION OF A GREAT CIRCLE ROUTE

Route Midpoint Distance from Stereographic Tangency Point, N. Miles	Great Circle Route Distance, N. Miles: 500	1000	1500	2000	2500	3000
0	0	0	0	0	0	0
100	0.1	0.5	1.2	2.1	3.4	4.9
200	0.3	1.1	2.4	4.3	6.8	9.8
300	0.4	1.6	3.6	6.4	10.1	14.8
400	0.5	2.1	4.8	8.6	13.5	19.7
500	0.7	2.7	6.0	10.7	16.9	24.6
600	0.8	3.2	7.2	12.9	20.3	29.6

For the underlying analysis, see Appendix H.

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TABLE A-9

SUMMARY OF GREAT CIRCLE AND FIXED ROUTE DISTANCES FLOWN FROM EASTERN U.S. TERMINALS

	Total Great Circle Distance (GCD) Nearest 10 N. Miles	Transition Path Distances, Nearest 5 N. Miles			En Route Waypoints	Longest Great Circle Segment	Number of Flights Filing OFF Route
		Dep. +	Arr. =	Sum (% of GCD)			
1. Kennedy NY to:							
Houston	1240	105	40	145 (12%)		1095	51
San Francisco	2230	105	65	170 (8%)	CYS[3]	1300 (2000)[3]	34
Los Angeles	2140	235	225	460 (21%)		1680	36
2. Newark NY to:							
San Francisco	2230	100	65	165 (7%)	CYS[3]	1310 (2000)[3]	51
Chicago	630	100	130	230 (37%)		400	12
3. Philadelphia, PA to:							
Chicago	590	45	130	175 (30%)		415	0
4. Pittsburg, PA to:							
Atlanta	440	50[2]	85	135 (31%)		250	4
5. Buffalo, NY to:							
Atlanta	600	50	85	135 (23%)		465	0

TABLE A-9

(Cont'd)

	Total Great Circle Distance (GCD) Nearest 10 N. Miles	Transition Path Distances, Nearest 5 N. Miles Dep.	+ Arr.	= Sum (% of GCD)	En Route Waypoints	Longest Great Circle Segment[1]	Number of Flights Filing OFF Route
6. Atlanta, GA to:							
Newark	650	150	100	250 (38%)		400	0
Charlotte	180	70	25	95 (15%)		85	0
San Francisco	1850	125	365[2]	490 (26%)		1360	22
Los Angeles	1700	125	130	255 (15%)		1445	160
Seattle	1890	90	125	215 (11%)		1675	78
Chicago	500	150	100	250 (50%)		250	14
Pittsburg	440	140	50[2]	190 (43%)		250	57
Buffalo	600	140	40	180 (30%)		420	197
Miami	530	0	90	90 (17%)		440	0
7. Charlotte, NC to:							
LaGuardia	470	0	100[1]	100(21%)		370	65
8. Miami, FL to:							
Chicago	1030	185	100	285 (28%)		745	130
Los Angeles	2040	175	130	305 (15%)	EWM	1250	307
San Francisco	2240	175	365	540 (24%)	NEPTA	1420	377
	2.220	2315	2545	4860		17025	1595

Average Total Distances:

Above Airport Pairs(21) = 1150 | 110 | 120 | 230 (20%)

Average Great Circle Segments:

Above OFF-Routes (21) = 810
Weighted by Flights Using(1595) = 1100

1. Longest great circle segment on route between each airport pair.

2. If more than one transition path is applicable, the shortest one was used.

3. Farly in the data collection period, JFK and EWR to SFO flights were made without the CYS turnpoint restriction. For those flights, the great circle distance flown was about 2000 miles (per private conversation with AAT-330).

TABLE A-10

SUMMARY OF GREAT CIRCLE AND FIXED ROUTE DISTANCES FLOWN FROM CENTRAL U.S. TERMINALS

	Total Great Circle Distance (GCD) Nearest N. Miles	Transition Path Distances, Nearest 5 N. Miles: Dep.	+ Arr.	= Sum (% of GCD)	En Route Waypoints	Longest Great Circle Segment[1]	Number of Flights Filing OFF Route
1. Chicago, IL to:							
Newark	630	80	200	280 (44%)		350	20
Philadelphia	590	75	85	160 (27%)		430	0
Miami	1030	110	90	200 (54%)		830	18
Los Angeles	1600	170	225	395 (25%)		1200	13
2. Houston, TX to:							
Kennedy	1240	80	135	215 (17%)		1025	86
San Francisco	1430	235	215	450 (34%)		980	0
	6520	750	950	1700		4815	137

Average Total Distances:

Above Airport Pairs(6) = 1090	125	160	285 (26%)	

Average Great Circle Segments:

Above OFF-Routes (6) = 800
Weighted by Flights Using(137) = 920

1. Longest great circle segment on route between each airport pair.

TABLE A-11

SUMMARY OF GREAT CIRCLE AND FIXED ROUTE DISTANCES FLOWN FROM WESTERN U.S. TERMINALS

	Total Great Circle Distance (GCD) Nearest 10 N. Miles	Transition Path Distances, Nearest 5 N. Miles: Dep. +	Arr. =	Sum (% of GCD)	En Route Waypoints	Longest Great Circle Segment[1]	Number of Flights Filing OFF Route
1. Seattle, WA to:							
Atlanta	1890	40	90	130 (7%)		1760	3
Los Angeles	630	25	140	165 (10%)		1525	0
2. San Francisco, CA to:							
Houston	1430	205	70	275 (19%)	CEARA	640	0
Miami	2240	205	175	380 (17%)	NEPTA	1400	0
Atlanta	1850	205	125	330 (18%)		1520	44
Kennedy	2230	205	200	405 (62%)		1825	0
Newark	2230	205	200	405 (18%)		1825	0
3. Los Angeles, CA to:							
Chicago	1600	110	90	200 13%)	LAS	1300	45
Kennedy	2140	110	200	310 (14%)		1830	67
Atlanta	1700	115	125	240 (13%)		1460	0
Miami	2040	185[2]	175	360 (16%)	EWM	1045	33
Seattle	830	100[2]	25	125 (22%)		755	0
	20810	1710	1615	3325		16885	192

Average Total Distances:

Above Airport Pairs (12) = 1730 — 140 — 135 — 275 (16%)

All Airport Pairs (39) = 1320

Average Great Circle Segments:

Above OFF-Routes (12) = 1410
Weighted by Flights Using (192) = 1500

All OFF-Routes (39) = 1000
Weighted by Flights Using (1924) = 1130

1. Longest great circle segment on route between each airport pair.

2. If more than one transition path is applicable, the shortest one was used.

One way to do the latter would be to (1) transform direct route segments of greater than some parameter value in length to gnomonic coordinates, (2) find, say, the point(s) where the filed route crosses center and/or sector boundaries, and (3) transform these boundary crossing points back into the stereographic plane for subsequent processing of that direct route segment.* This approach has the following advantages:

- The transformation algorithms already exist in NAS A.3 software, though they are not used in exactly this way.

- It preserves the basic route conversion logic of the NAS A.3 software.

It also has some disadvantages:

- Using two coordinate systems in the route conversion process is not as simple as using one, leaving more room for errors and inefficiencies to creep in.

- Both the stereographic and the gnomonic coordinate systems rely on projecting earth coordinates into flat planes tangent to the earth, resulting in unavoidable projection errors. Some approximating equations are also used which introduce additional errors.

Another approach that might be studied in the context of the computer replacement program is the conversion of filed routes directly into spherical coordinates for subsequent processing. While such computations were clearly out of the question when NAS Stage A was designed, due to the computer technology constraints of the 1960s, such constraints do not necessarily apply in the current decade. The basic approach would be to:

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* A great circle route plots as a straight line in gnomonic coordinates.

1. Convert all filed flight plan routes into expected paths over an assumed spherial earth. Treat planned altitudes as values perpindicular to those spherical paths.

2. Perform surveillance and tracking functions in that same spherical coordinate system. This would, incidentally, improve the system's ability to accurately place tracked position data provided by remotely located surveillance sites.

3. Internally compute all intersections of interest in spherical coordinates.

4. When needed for such functions as flat-surface display make-up, transform data in spherical coordinates to stereographic (flat surface) coordinates.

This approach has the following advantages:

- It avoids the projection and approximation errors of the stereographic and gnomonic systems by providing a spherical coordinate system for an approximately spherical earth (oblate errors are quite small).

- It is conceptually straightforward and may be simpler to implement.

And only one known disadvantage:

- Some additional analytical work needs to be done (or found) before an intelligent comparison of alternatives and a design decision can be made.

Clearly, this will be an issue if the filing of long random direct routes were ever to become popular.

The problem is also aggrevated if ARTCCs are consolidated into fewer than 20 centers, since the distance that a great circle route can be from any given center's stereographic tangency point is increased.

APPENDIX B

FUEL BURN RATES ASSUMED FOR ANALYSIS OF TYPICAL FUEL PENALTIES

TABLE B-1

TYPICAL CLIMB MILES AND FUEL BURNS FOR A B727-225A

- International Standard Atmosphere (ISA), IAS-10, ISA+20°
- No Wind
- Climb Speed Schedule:

  0.76 Mach after Crossover
  300 Kts. before Crossover
  250 Kts. to 10,000 MSL

CLIMB TO FLIGHT LEVEL	110 Klbs.			160 Klbs.								
	ISA			ISA-10°			ISA			ISA+20°C		
	Dist. Miles	Fuel Lbs.	Gals.	Dist. Miles	Fuel Lbs.	Gals.	Dist. Miles	Fuel Lbs.	Gals.	Dist. Miles	Fuel Lbs.	Gals.
410	. . . . Maximum Altitude for Aircraft Type											
390	87	3700	544	78	3600	530	160	6600	971	294	9200	1353
380	82	3600	530	73	3500	516	140	6100	898	243	8300	1221
370	77	3500	516	69	3400	500	128	5900	868	219	7800	1147
360	72	3400	500	64	3300	406	118	5600	824	201	7400	1088
350	69	3300	486	61	3200	471	110	5400	794	186	7100	1044
340	65	3300	486	58	3100	457	103	5200	765	173	6800	1000
330	62	3200	470	55	3000	441	97	5100	750	161	6500	957
320	59	3100	457	52	3000	441	92	4900	721	151	6300	927
310	56	3000	441	49	2900	427	87	4800	707	141	6000	882
300	53	2900	427	47	2800	412	82	4600	677	132	5800	853
290	51	2900	427	44	2700	398	76	4500	662	120	5500	810
280	48	2800	412	42	2700	398	70	4300	632	110	5300	780
270	45	2700	398	39	2600	382	65	4100	603	100	5000	736
260	42	2600	382	36	2500	369	60	3900	574	92	4800	707

TABLE B-1

(Cont'd)

CLIMB TO FLIGHT LEVEL	110 Klbs. ISA			160 Klbs. ISA-10°			160 Klbs. ISA			160 Klbs. ISA+20°C		
	Dist. Miles	Fuel Lbs.	Gals.	Dist. Miles	Fuel Lbs.	Gals.	Dist. Miles	Fuel Lbs.	Gals.	Dist. Miles	Fuel Lbs.	Gals.
250	39	2500	369	34	2400	353	55	3800	559	84	4500	662
240	36	2400	353	31	2300	339	51	3600	529	77	4300	632
230	33	2300	339	29	2200	324	47	3500	516	71	4100	603
220	31	2200	324	27	2100	310	44	3300	486	65	3900	574
210	29	2100	310	25	2100	310	40	3200	471	59	3700	544
200	27	2000	294	23	2000	294	37	3000	441	54	3500	515
190	25	2000	294	21	1900	280	31	2800	412	45	3200	471
180	23	190	29	20	1800	266	26	2500	368	36	2900	427
160	19	170	25	17	1600	336	23	2400	353	32	2700	398
140	16	150	22	14	1500	221	21	2200	324	29	2500	369
130	14	150	22	12	1400	207	16	2000	294			
120	13	140	21	11	1300	191						
100	10	120	19	9	1200	177						

Notes

(1) From a B727-225A Performance and Planning Manual, 9-03-80.

(2) Allowances for Takeoff and Acceleration to Climb Speed included.

(3) Gallons = Lbs. + 6.8.

TABLE B-2

FUEL BURN RATES VS ALTITUDE FOR A B727-225A

160 Klbs, Standard Day, No Wind, @ Long Range Cruise (LRC) Speed

FLIGHT	LRC SPEED			FUEL BURN RATES		
LEVEL	MACH (1)	IAS (1)	TAS (2)	Lbs/Hr/Engine (1)	Lbs/Minute (3)	Gallons/N Mile (4)
		Knots	Knots (Miles/Min.)			
390 (Not achievable at 160 Klbs)						
370	.796	258	458 (7.6)	3124	156 (+4%)	3.0 (+7%)
350	.803	273	463 (7.7)	3021	151	2.9
330	.801	284	466 (7.8)	2996	150 (base)	2.8 (base)
310	.792	293	464 (7.7)	3027	151	2.9
290	.777	300	458 (7.6)	3076	154 (+3%)	2.95 (+5%)
280	.769	303	455 (7.6)	3111	156 (+4%)	3.0 (+7%)
270	.760	306	451 (7.5)	3145	157	3.1
260	.750	308	448 (7.5)	3178	159	3.1
250	.740	310	444 (7.4)	3209	160	3.2
240	.729	311	439 (7.3)	3244	162	3.3
230	.718	313	434 (7.2)	3281	164	3.4
220	.707	314	430 (7.2)	3317	166	3.4
210	.696	315	424 (7.1)	3358	168	3.5
200	.685	316	420 (7.0)	3401	170	3.6

TABLE B-2

(Cont'd)

FLIGHT LEVEL	LRC SPEED MACH (1)	IAS (1)	TAS (2)	FUEL BURN RATES Lbs/Hr/Engine (1)	Lbs/Minute (3)	Gallons/N Mile (4)
		Knots	Knots (Miles/Min.)			
190	.674	317	414 (6.9)	3435	172	3.7
180	.663	317	409 (6.8)	3469	174	3.8
170	.652	318	403 (6.7)	3499	175 (+14%)	3.8 (+36%)
160	.641	319	399 (6.6)	3530	176	3.9
150	.631	319	394 (6.6)	3557	178	4.0
...						
100	.580	322	371 (6.2)	3756	188 (+25%)	4.5 (+58%)

Notes

(1) From a B727 - 225A *Performance and Planning Manual*, 9-1-72

(2) TAS = $\left[40 + 600 \text{ Mach} - h \text{ (Kft.)}/0.6\right]$ for $h \leq 36$ Kft.; TAS = $\left[600 \text{ Mach} - 20\right]$ for $h > 36$ Kft.

(3) (Lbs./Hr./Engine) x (3 Engines) + (60 Minutes/Hr.)

(4) $\left[\text{(Lbs./Min.)} + \text{(Miles/Min.)}\right]$ + (6.8 Lbs./Gallon)

TABLE B-3

TYPICAL DESCENT MILES AND FUEL BURNS FOR A B727-225A

- o All Temperatures
- o No Wind
- o Descent Speed Schedule as Shown

DESCENT FROM PRESSURE ALTITUDE	"55% N1 CLEAN" M.80/280/250 (Notes 2, 4)			"NORMAL DESCENT" M.80/300/250 (Notes 3, 5)			"IDLE, CLEAN" M.85/350/250 (Notes 2, 4)			"IDLE, CLEAN" M.85/350/250 (Notes 3, 5)		
Altitude, 100's of Feet	Time, Minutes	Fuel, Gals.	Distance, N. Miles	Time, Minutes	Fuel, Gals.	Distance, N. Miles	Time, Minutes	Fuel, Gals.	Distance, N. Miles	Time, Minutes	Fuel, Gals.	Distance, N. Miles
410	28	301	167				16	250	103			
390	27	298	162	23	268	115	16	248	101	20	253	103
370	27	295	152	22	265	110	16	247	97	20	251	99
350	26	293	148	22	263	106	15	244	93	19	249	96
330	25	288	144	21	260	101	15	243	89	19	247	92
310	24	284	135	20	258	97	14	240	85	18	245	89
290	23	278	126	19	255	92	13	238	82	18	243	85
270	21	272	117	19	251	86	13	237	78	17	241	82
250	20	266	108	18	248	80	12	234	73	17	239	78
230	19	260	99	18	245	75	12	231	68	16	236	73
210	17	254	90	17	241	70	11	228	63	16	234	69
190	16	247	81	16	237	64	10	223	58	15	231	64
170	14	238	71	15	233	59	10	220	53	14	228	60
150	12	229	61	15	228	54	12	216	48	14	225	56
100	8	200	35	13	215	42	8	204	37	12	217	46
50	3	172	14	9	189	25	3	172	14	9	189	25

Notes:

1. Speed Schedules are shown in parenthesis; e.g., "Mach 85 to 350 knots at crossover; then reduce to 250 knots before descent below 10,000 feet".

2. Fuel for a straight-in approach is included.

3. Fuel for (a) a straight-in ILS approach with gear and flaps extended, and (b) 2 minutes air maneuver fuel allowance at 5000 feet.

4. From a B727-225A Performance and Planning Manual, 6-23-75.

5. From a B727-225A Performance and Planning Manual, 9-03-80. (Received by the author after the bulk of the work was completed for this report. Thus, "IDLE, CLEAN", rather than "NORMAL DESCENT", was used for most analyses.)

APPENDIX C

FUEL BURN ANALYSIS FOR DCA ARRIVALS
RIC..SABBI..DCA

o **ALTITUDE PROFILES**

A - Current: sec SOP Restrictions

B - Unrestricted Idle Clean Descent*

C - Unrestricted Partial Thrust Descent*

FUEL BURN DIFFERENCES, LANDING NORTH

Profile B vs A (Idle Clean vs Current):

270 vs 330 for 76 miles:

(3.1 - 2.8) gals./mi. x 76 miles = 22.8 gals.

170 vs 270 for 12 miles:

(3.8 - 3.1) gals./mi. x 12 miles = 8.4 gals.
Penalty due to Restrictions = 31.2 gals.

Profile C vs A (Partial Thrust vs Current):

270 vs 330 for 34 miles:

(31 - 2.8) gals./mi. x 34 miles = 10.2 gals.

---

* But slow to 250 knots before descending below 10,000 MSL.

APPENDIX C

(Cont'd)

Profiles C vs B (Partial Thrust vs Idle Thrust):

FL330 to Runway at Idle Clean:

89 miles, 1650 lbs.	6.8 gals./lb.	=	242.6 gals.
+55 miles @ 2.8 gals./mile		=	154
144 miles			396.6 gals.

FL330 to Runway at 55% N1 Clean:

144 miles, 1960 lbs. 6.8 gals./lb. = 288.2 gals.

Profile C vs B Difference = 108.4 gals.

FUEL BURN DIFFERENCES, LANDING SOUTH:

Add 20 miles at 100 vs 330:

(4.5 - 2.8)) gals./mi. x 20 miles = 34 gals.

- **ROUTE PROFILES**

ILM.J165.STOSH.J77.RIC vs ILM..RIC:

(123 + 74) = 197 miles via dogleg
191 miles direct
6 miles

6 miles x 2.8 gals./mi. = 16.8 gals.

#1326E

APPENDIX D

FLIGHT STRIP ANALYSIS OF SABBI ARRIVALS TO WASHINGTON, D.C.

The following data is based on an analysis of flight progress strips from the Washington Center for Friday, 10 October 1980. This day was a busy one for this center: about 6100 flights were handled, which is 97% of this center's all-time high of 6300 flights.

TABLE D-1

SUMMARY RESULTS: SABBI ARRIVALS VS J14 SOUTHBOUNDS

Friday, 10 October 1980

SHIFT	EDT @ RIC	SABBI Arrivals before Descent West of J165	CHS.J165	ILM...	Descents from Altitude	Potential Competitors Over Shift	J14 Southbounds over Richmond	
MID	0-8	0	0	1	1 @ 370	0	0	@/Above 370
					1 flight/shift		1	@ 350
							1	climbing to 350
							1	@ 310
							3	1 flight every 3 hours
DAY	8-16						1	climbing to 410
							4	@ 390
		2	5	1	8 @ 370	66	1	descending from 390
							36	@ 350
		1	3	8	12 @ 330	29	5	transitioning to/from 350
							15	@ 310
				1	1 @ 290	9	5	transitioning to/from 310
							2	@ 280
		1	1		2 @ 270	2	2	descending from 280
							0	@ 260
				1	1 @ 250	0	0	transitioning to/from 260
		4	9	11			71	9 flights per hour
EVE	16-24						2	@ 390
		1	1		2 @ 370	26	0	transitioning to/from 390
							11	@ 350
		3	5	4	12 @ 330	15	1	descending from 350
		4	6	4			11	@ 310
							1	transitioning to/from 310
							2	@ 280
		39 DCA Arrivals via SABBI					28	4 flights per hour

TABLE D-2

WASHINGTON NATIONAL ARRIVALS FROM MIAMI...VIA STOSH

Typical Origins: Miami (MIA) Myrtle Beach (MYR)
Palm Beach (PBI)
Fort Lauderdale Executive (FXE)

SOP for Sector 35 (ILM High): Route DCA Arrivals via:

...ILM.J77.STOSH.J165.RIC.V376...DCA

SOP for Sector 36 (RDU High): Clear DCA Arrivals to enter Sector 20 at (below) 270, UOC (unless otherwise coordinated).

SOP for Sector 20 (FAK Int.): Clear DCA Arrivals to enter Sector 14 (IRONS Low) at 170, UOC.

SOP for Sector 20 (IRONS Low): Clear DCA Arrivals to enter DCA TRACON:

Turbojet: Cross SABBI at 10,000' and 250 knots, regardless of the direction of landing.

Piston: Cross IRONS at 4,000' regardless of the direction of landing.

TURBOJET TRAFFIC ON FRIDAY, 10 OCTOBER 1980

SHIFT	EDT at ILM	AIRCRAFT TYPES & ALTITUDES		SOP DEVIATIONS
MID	0-8	1 N265 Sabreliner	370	
DAY	8-9	0		
	9-10	2 B727, DC9	330	
	10-13	0		
	13-16	1 N265	370	
		5 B727, DC9	330	+1 Direct*
		1 B737	290	
		0 B737	250	+1 Direct*
		9		+2
EVE	16-24	1 B727	330	+2 Directs*
		0 B737	330	+1 Direct*
		1		+3
TOTAL		11 SOP + 5 Directs		

* Apparent cleared route = ...AR7.HAH..RIC...DCA.
Strips found for Sectors 35, 33, 20, but not 36.

TABLE D-3

WASHINGTON NATIONAL ARRIVALS VIA CHS.J165 RIC

Typical Origins:	Tampa (TPA) Jacksonville (JAX) Savannah (SAV) Charleston (CHS)
SOP for Sector 36 (RDU High):	Clear DCA Arrivals to enter Sector 20 at (below) 270, UOC (unless otherwise coordinated).
SOP for Sector 20 (FAK Int.):	Clear DCA Arrivals to enter Sector 14 (IRONS Low) at 170, UOC.
SOP for Sector 20 (IRONS Low):	Clear DCA Arrivals to enter DCA TRACON: Turbojet: Cross SABBI at 10,000' and 250 knots, regardless of the direction of landing. Piston: Cross IRONS at 4,000' regardless of the direction of landing.

SHIFT	EDT at RIC	AIRCRAFT and HIGHEST ASSIGNED ALTITUDE*		
MID	0-8	0		
DAY	8-9	0		
	9-11	1 B727		370
		1 DC9		330
	11-12	0		
	12-15	4 C141		370 (from CHS)
		2 B727, DC9	330	
		1 B707		270
	15-16	0		
		9		
EVE	16-17	1 B727		370
		3 DC9, B727	330	
	17-19	0		
	19-20	2 DC9, B727	330	
	20-24	0		
		6		
TOTAL		15		

* No exceptions to SOP were found.

TABLE D-4

WASHINGTON NATIONAL ARRIVALS VIA RICHMOND FROM ROUTES WEST OF J165

Typical Origins: Atlanta (ATL, FTY)
Greenville-Spartanburg, SC (GSP)
Charlotte, NC (CLT)
Orlando, (MCO)
Eglin AFB (VPS)
Pensacola NAS (NPA)

SOP for Sector 36 (RDU High): Clear DCA Arrivals to enter Sector 20 at (below) 270, UOC (unless otherwise coordinated).

SOP for Sector 20 (FAK Int.): Clear DCA Arrivals to enter Sector 14 (IRONS Low) at 170, UOC.

SOP for Sector 20 (IRONS Low): Clear DCA Arrivals to enter DCA TRACON:

Turbojet: Cross SABBI at 10,000' and 250 knots, regardless of the direction of landing.

Piston: Cross IRONS at 4,000' regardless of the direction of landing.

SHIFT	EDT at RIC	AIRCRAFT TYPES & ALTITUDES		SOP DEVIATIONS
MID	0-8	0		
DAY	8-9	1 H525	330	Entered Sector 33 at 330
	9-10	0		
	10-11	1 B727	370	
	11-14	0		
	14-16	1 T39	370	May have entered 33
		1 B707	270	
		4		
EVE	16-17	0		
	17-18	1 G2	370	Entered 33 descending
		3 B727, DC9,	330 Citation	
	18-24	0 C500		
		4		
TOTAL		8		

TABLE D-5

SOUTHBOUNDS VIA J14 OVER RICHMOND

o <u>New York to Miami, Nassau</u>

LaGuardia (LGA) Newark (EWR)	...J14.RIC.J40.ILM.AR1...	Miami (MIA) Ft. Lauderdale (FLL) Palm Beach (PBI)
Kennedy (JFK)	...J14.RIC..HAH.AR7...	Nassau (ZQA)

SHIFT	EDT at RIC	AIRCRAFT TYPES & ALTITUDES		
MID	0-8	0		
DAY	8-10	0		
	10-15	1	G2	390
		12	B727, L1011, DC8	350
		6	B727	310
		19		
	15-16	0		
EVE	16-18	0		
	18-20	1	G2	390
		2	B727	350
		2	B727, A300	310
		1	B727	280
		6		
	20-24	0		
TOTAL		25		

TABLE D-5

(Cont'd)

o **New York to Southeast U.S. via Raleigh, N.C.**

Boston (BOS)		Tampa (TPA)
Windsor Locks (BDL)		Fayetteville NC (FAY)
Kennedy (JFK)	...J14.RIC.J52.RDU...	Columbia SC (CAE)
LaGuardia (LGA)		New Orleans (MSY)
Newark (EWR)		Houston (IAH)
Philadelphia (PHL)		

SHIFT	EDT at RIC	AIRCRAFT TYPES & ALTITUDES	
MID	0-8	1 DC9	310
DAY	8-9	0	
	9-10	2 B727	350
	10-11	0	
	11-14	3 B727, DC9, B737	350
		3 B727, DC9, N265	310
		1 B727	280
		9	
	14-16	0	
EVE	16-18	0	
	18-20	3 B727, T39 Sabreliner	350
		4 B727, L1011	310
	20-24	0	
		7	
TOTAL		17	

TABLE D-5

(Cont'd)

o **New York to Florida via Charleston, S.C.**

LaGuardia (LGA)		Savannah (SAV)
Newark (EWR)	...J14.RIC.J165.CHS...	Jacksonville (JAX)
Kennedy (JFK)		Orlando In'l (MCO)
Teterboro (TEB)		Tampa (TPA)
Philadelphia (PHL)		St. Petersburg (PIE)
		Palm Beach (PBI)

SHIFT	EDT at RIC	AIRCRAFT TYPES & ALTITUDES	
MID	0-8	1 B727	350
DAY	8-9	0	
	9-16	3 B747S, LR35, L329 Jetstar	390
		9 B727, A300, N265 Sabreliner	350
		6 B727, DC9, A300	310
		19	
	16-17	0	
EVE	17-20	1 N265	390
		4 B727, DC9, FFJ	350
		5 B727, A300, DC9	310
		10	
	20-24	0	
TOTAL		29	

TABLE D-5

(Cont'd)

o <u>New York to Raleigh-Durham, N.C. via STEMM</u>

LaGuardia (LGA)
Newark (EWR) ..J14.RIC.J14.V3.STEMM..RDU
Trenton (TTN)
Philadelphia (PHL)

SHIFT	EDT at RIC	AIRCRAFT TYPES & ALTITUDES	
MID	0-8	0	
DAY	8-9	2 B737, DC9	descending from 350, 310
	10-13	0	
	13-16	1 LR35	descending from 390
		3 G2, B727	descending from 350
		2 FA28, B727	descending from 280
		8	
EVE	16-17	1 DC9	descending from 310
	17-18	1 B737	descending from 350
	18-24	0	
		2	
TOTAL		10	

TABLE D-5

(Cont'd)

o **New York to the Southeastern U.S. via Greensboro, N.C. (GSO)**

Boston (BOS)		
Providence (PVD)		
LaGuardia (LGA)	...J14.RIC.J14.GSO...	Greensboro (GSO)
Newark (EWR)		Charlotte NC (CLT)
Philadelphia (PHL)		Atlanta (ATL)

SHIFT	EDT at RIC	AIRCRAFT TYPES & ALTITUDES	
MID	0-8	0	
DAY	8-9	3 B727, DC9	350
	9-10	0	
	10-13	6 DC9, B737, C141	350
		1 FA28	280
	13-15	0	
	15-16	1 B727	350
		11	
EVE	16-17	0	
	17-23	2 DC9	350
		1 B727	280
		3	
	23-24	0	
TOTAL		14	

TABLE D-5

(Concl'd)

o **Baltimore ... to Florida ... via Richmond**

Baltimore (BWI) Dover, DE (DOV)	...J14.RIC.J52.RDU...	Tampa (TPA)
	or	
	...J14.RIC.J165.CHS...	Charleston SC (CHS) Orlando (MCO) Ft. Lauderdale (FLL)
	or	
	...J14.RIC.J40.ILM...	Miami (MIA) Boca Raton (BCI)
	or	
	...J14.RIC.EKV.C1181...San Juan (SJU)	

SHIFT	EDT at RIC	AIRCRAFT TYPES & ALTITUDES	
MID	0-8	1 C5A	climbing to 350
DAY	8-10	4 B727, DC9	climbing to/at 350
		1 B727	climbing to 310
		1 DC9	requesting 310
		6	
	10-12	0	
	12-13	1 DC9	climbing to 310
	13-14	0	
	14-16	1 LR25	climbing to 410
EVE	16-24	0	
TOTAL		9	

APPENDIX E

FUEL BURN ANALYSIS FOR NORFOLK DEPARTURES TO CHICAGO

ROUTE

A - Current: RIC..CRW..PKB..ROD..FWA

229 + 62 + 118 + 67 = 476 N. Miles

B - Proposed: RIC..MOL..PKB..ROD..FWA

112 + 142 + 118 + 67 = 439 N. Miles

C - Direct: RIC..GVE..FWA

45 + 368 = 413 N. Miles

FUEL BURN DIFFERENCES @ FL350 For a B727-200:

ROUTE B vs A (Proposed vs Current):

476 - 439 = 37 N. Miles saved

37 miles x 2.9 gals./mi. = 107 gallons per trip saved

ROUTE C vs B (Ideal vs Proposed):

439 - 413 = 26 N. Miles saved

26 miles x 2.9 gals./mi. = 75 gallons per trip saved

ROUTE C vs A (Ideal vs Current):

107 + 75 = 182 gallons per trip saved

APPENDIX F

FLIGHT STRIP ANALYSIS OF NORFOLK AND RICHMOND DEPARTURES TO CHICAGO (ORD)

The following data is based on an analysis of flight progress strips from the Washington Center for Friday, 10 October 1980. This day was a busy one for this center: about 6100 flights were handled, which is 97% of this center's all-time high of 6300 flights.

Richmond (RIC)	...FAK.J24.CRW.J85.(PKB).J149.FWA...ORD
Norfolk (ORF)	or
Patrick Henry (PHF)	...FAK.J24.CRW..HNN..ROD..FWA...ORD

SHIFT	EDT at RIC or RIC 261/039	AIRCRAFT TYPES & ALTITUDES	
MID	0-8	1 B737	requesting 350
DAY	8-9	3 B737, B727	requesting 350
	9-10	0	
	10-11	1 B727	climbing to 350
	11-15	0	
	15-16	1 B737	requesting 350
		5	
EVE	16-17	0	
	17-18	2 B727	requesting 350
	18-24	0	
		2	
TOTAL		8 + 3 proposed departures not activated	
		(All were United or Piedmont flights)	

APPENDIX G

A REVIEW OF THE NORTHEAST AREA PROCEDURAL STUDY

The Northeast Area Procedural Study (NAPS) Report (Reference 2) contains an in-depth analysis of current ATC procedures in the areas controlled predominately by the New York ARTCC and its associated terminal facilities. It was sponsored jointly by the Air Traffic Divisions of FAA's Eastern and New England Regions and was performed by FAA facility representatives working with respresentatives of the various flying groups (ATA, NBAA, NCAA, various airlines, etc.). The purpose was to review user and facility complaints regarding ATC procedures in the northeast corridor. Quoting the executive summary, "Joint FAA/User meetings and work sessions ... resounded with one common plea: 'CONSERVE AVIATION FUEL'."

The NAPS Committee began its work in January 1980 and completed its report by the end of that year.

The basic approach taken by the NAPS committee was to study the validity of each complaint and to attempt to find a better solution for each validated problem. The study deals with some 37 validated problems, sorted into 8 categories. It states each validated problem and offers either (1) a rationale supporting present procedures, or (2) a recommended change to those procedures. The study states that if all the committee's recommendations were implemented, in excess of 3 million gallons of fuel could be saved annually.

This total of 3 million gallons was arrived at by (1) computing the potential fuel-saving of each recommended change to a procedural route or altitude restriction on a per-flight basis, (2) multiplying this unit saving by the estimated number of scheduled flights which could benefit annually, (3) summing the results, and (4) rounding the total up to account for unscheduled civil and military (non-airline) flights which would also benefit. This total indicates that significant improvements can be made if most-to-all of the committee's recommendations are implemented.

It should be pointed out, however, that the NAPS committee had to accept some constraints which limited how far they could go in recommending changes. For example, the currently implemented level of en route and terminal automation was taken as given. The additional benefits of ATC capabilities in development, but not yet implemented, were not taken into account. This of course was proper since they were mainly looking for attainable solutions within the context of the present ATC system. But for the purposes of this review, a change in perspective is made, and the NAPS study is appreciated in a new light.

The following reviews many of the problems that the NAPS committee dealt with and summarizes their recommendations, where such were made. In addition, the extent to which the post-NAPS procedure (i.e., the recommended or justified procedure) falls short of the ideal from the airspace user's point of view is pointed out. It is here that the attention of the developers of future improvements to the ATC system should be focused.

In taking this approach, this reviewer is not being critical of the NAPS effort, given its constraints. In fact, it was a commendable effort to find near-term improvements despite the obstacles.

Though the NAPS study focused primarly on operations in or related to the New York center's airspace, New York is not simply a "special case". The kinds of problems found here can also be found elsewhere, and their fuel impact is significant.

G.1. Characteristics of New York Center Sectorization and Procedures*

The New York Center has both domestic and oceanic ATC operations. The pre-strike sectorization of its airspace is as summarized in Table G-1. The major flows, sectors, and navaid locations are illustrated in Figures G-1, G-2, and G-3 for the high altitude structure. Table G-2 names the 3 and 5 letter fixes shown in the figures.

Some observations are:

1. The New York domestic ATC airspace is highly structured: Of the 20 domestic air route centers, it is by far the smallest, especially if the offshore airspaces within its boundary are excluded - see Figure G-4. For example, the Washington Center, which also is one of the smaller centers, has twice the area of the New York domestic center (140K versus 74K square miles).

   However, because of the high traffic demands within a relatively small region of airspace, the New York center has found it necessary to create a large number of sectors - 43, compared to Washington Center's 36. It also procedurally segregates specific traffic flows to different sectors, at least during busy hours - see Figures G-1 and G-2.

* The following is reproduced from Reference 3.

TABLE G-1

NEW YORK CENTER SECTORIZATION

as of April 1981

West | East

North

Area D Sectors (7)

Hancock Hi 33
Huguenot Hi 34
Stony Fork Hi 49

Ellis Int 36

Binghampton Lo 36
Lake Henry Lo 51
Sparta Lo 36

Area E Sectors (6)

Kingston Hi 88

Stewart Lo 89
Pauling Lo 90
Carmel Lo 71
Bridgeport Lo 87

Catskill Lo ... 72
(under Stewart & Pauling Lo)

Area F Sectors (9+1)

Hampton Hi 66
Atlantic Hi ... 65

Micke Lo 68
Sardine Lo 67

Oceanic CTA/FIR:
(non-radar)
Champ 82
Smelt 83

Area G Sectors (4)

Milton Hi 75

Swissdale Lo 93
Wilkes-Barre Lo 91
Allentown Lo 92

Area C Sectors (5+4)

Colts Neck Hi 56

Solberg Lo(Hi) 55
Manta Lo 39
Sates Lo 40
Millville Lo 41

Departure Clearances for:
Philadelphia/McGuire . 57/58
Kennedy Int'l 59
Newark 60
LaGuardia/White Plains 61/62

Mercury Hi ..... 84 (has VHF)
Germini Hi 85

Apollo Lo 86

Air Movements
Info Service:

AMIS Sector 81

Area A Sectors (5)

East Texas Hi 11
Harrisburg Hi 9

Middletown Int. 27
(over Amish Lo)

Amish Lo 25
Lancaster Lo 26
Modena Lo 10

Area B Sectors (6)

Coyle Hi 2
Sea Isle Hi 3

New Castle Lo 4
Woodstown Lo 19
Kenton Lo 17
Atlantic City Lo ... 18

Sector Summary*:

High 12
Intermediate 2
Low 24
Oceanic 5

43

South

*Does not include departure clearance or AMIS sectors, flow control, or metering positions

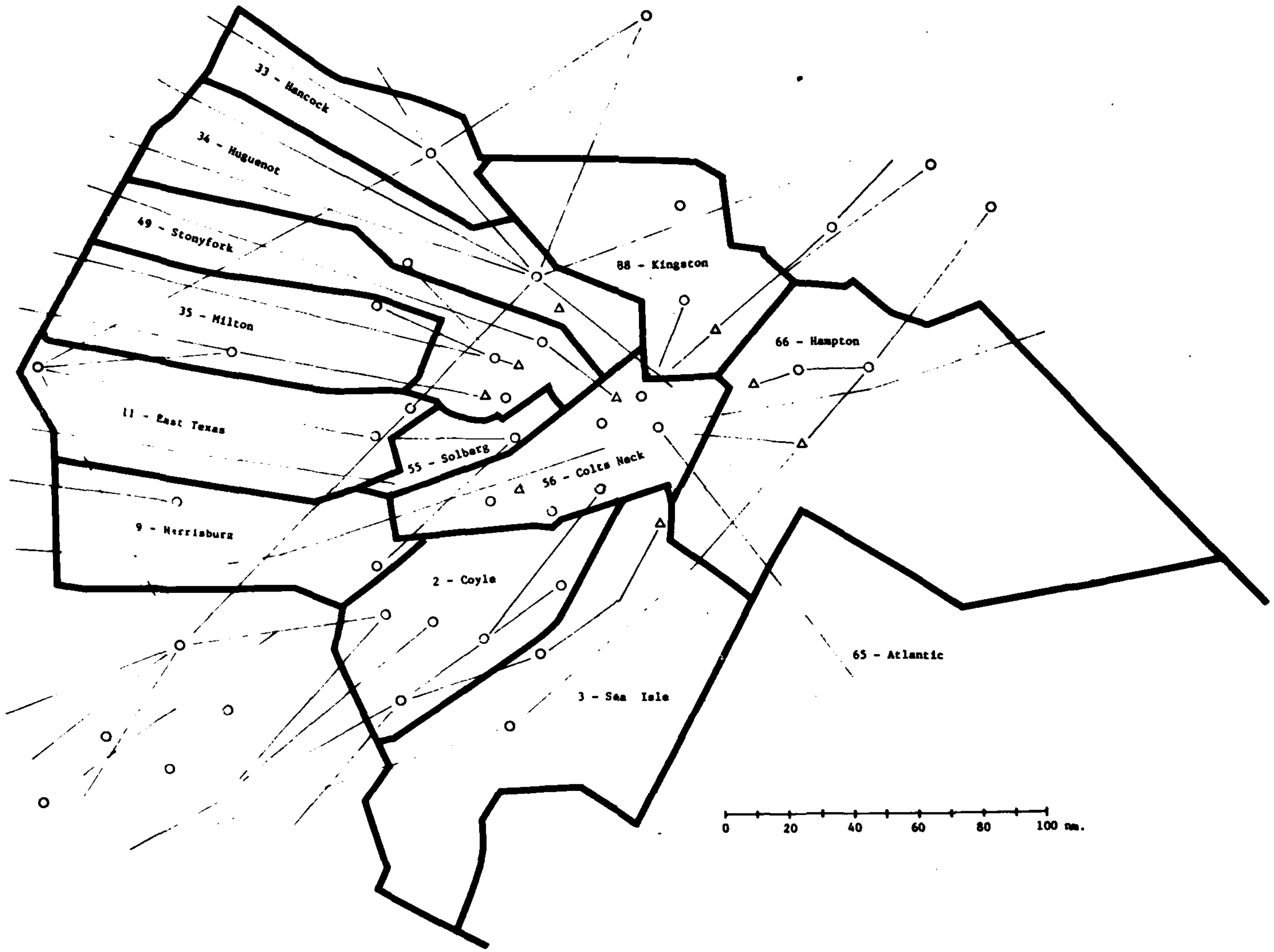

FIGURE G-1
NEW YORK CENTER: HIGH ALTITUDE SECTORIZATION

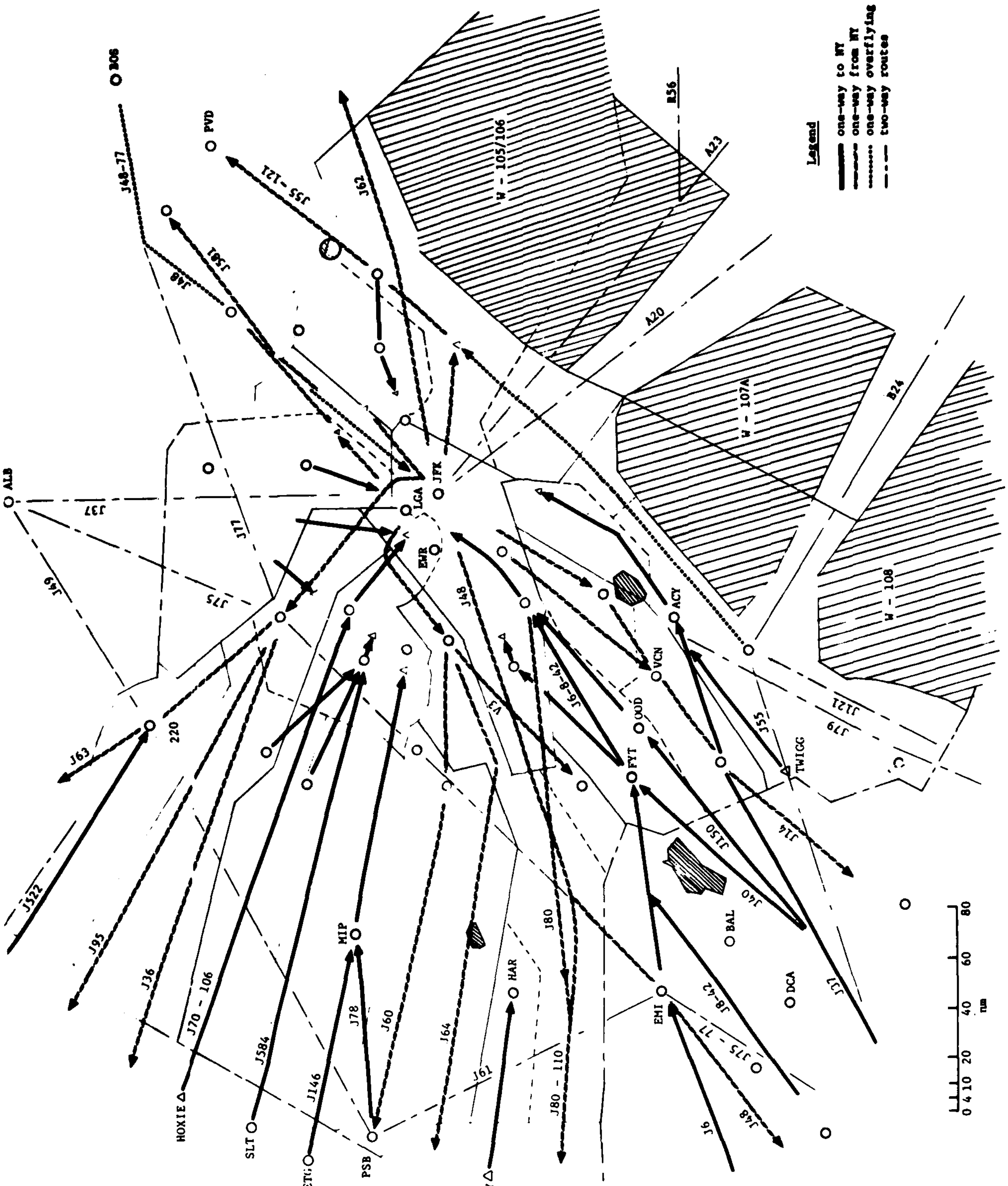

FIGURE G-2
NEW YORK CENTER: MAJOR HIGH ALTITUDE TRAFFIC FLOWS

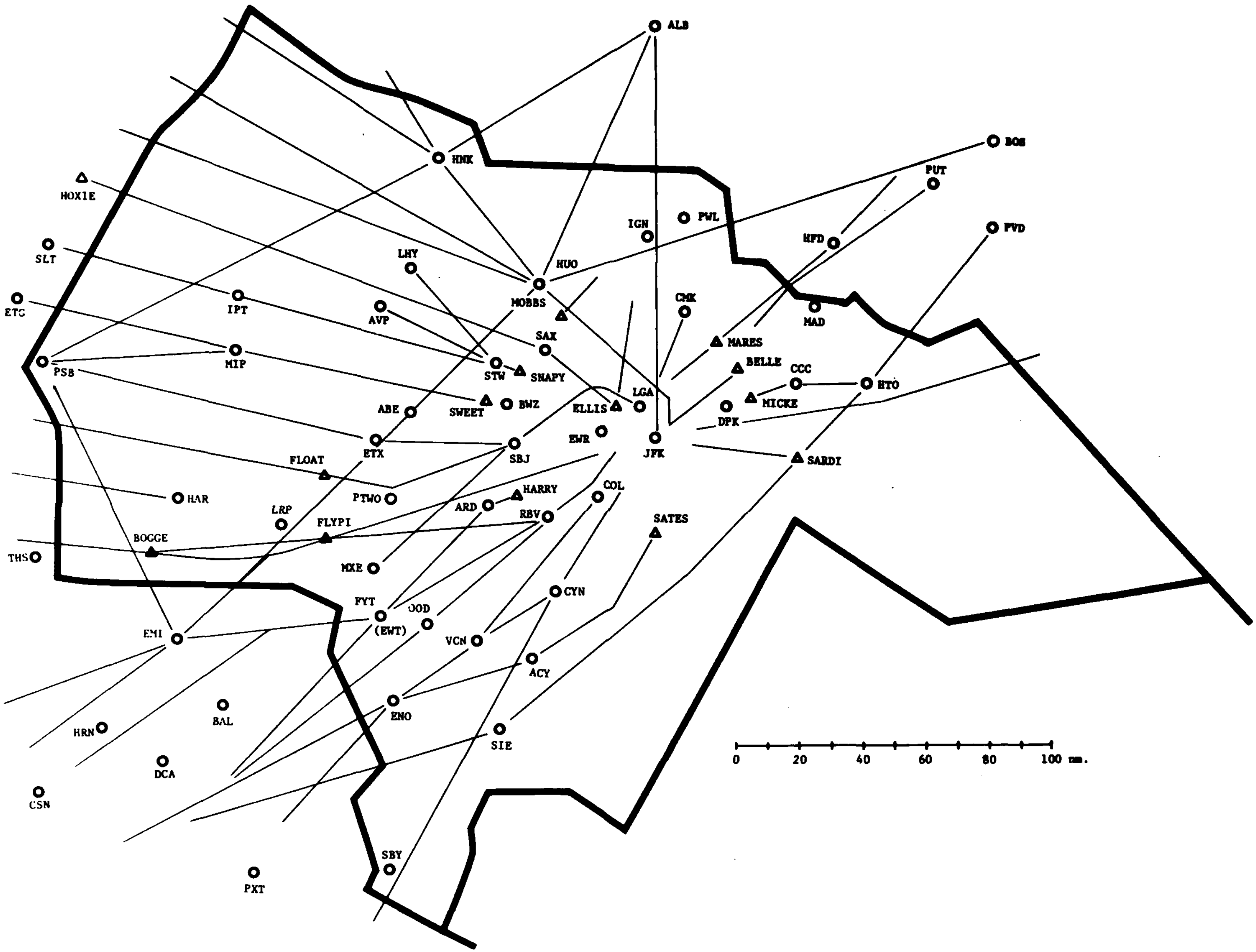

FIGURE G-3
NEW YORK CENTER: MAJOR NAVAIDS AND INTERSECTIONS

TABLE G-2

IMPORTANT NEW YORK CENTER FIXES

Fix	Fix Name
ABE	Allentown, PA
ACY	Atlantic City, NJ
ARD	Yardley, PA
ALB	Albany, NY
AVP	Wilkes-Barre/Scranton, PA
BAL	Baltimore, MD
BELLE	JFK Departure Fix
BOGGE	Departure Transition Fix (OFF)
BOS	Boston, MA
BWZ	Broadway VOR/DME
CCC	Calverton, NY
CMK	Carmel, NY
COL	Colts Neck, NJ
CSN	Casanova, VA
CYN	Coyle, NJ
DCA	Washington, DC.
DPK	Deer Park, NY
ELLIS	JFK Arrival Fix
EMI	Westminister, MD
ETG	Keating, PA
ETX	East Texas, PA
EWR	Newark Airport
FLOAT	Departure Transition Fix (OFF)
FLYPI	Departure Transition Fix (OFF)
EWT	New Castle, DE
FYT	Wilmington/Fatima, DE
HAR	Harrisburg, PA
HFD	Hartford, CT
HNK	Hancock, NY
HOXIE	Arrival Transition Fix (OFF)
HRN	Herndon, VA

Notes:

1. OFF = Operation Free Flight (see Appendix A)

2. Three letter fixes are airports or VOR/DME locations. Five letter fixes are published radial intersections.

#1374E

TABLE G-2

(Cont'd)

Navaid	Place Name
HTO	Hampton, NY
HUO	Huguenot, NY
IGN	Kingston, NY
JFK	J. F. Kennedy Airport
LGA	LaGuardia Airport
IPT	Williamsport, PA
LHY	Lake Henry VORTAC
LRP	Lancaster, PA
MAD	Madison, CN
MARES	LGA/EWR Departure Fix
MICKE	JFK Arrival Fix
MIP	Milton, PA
MIROY	EWR Arrival Fix
MOBBS	EWR Arrival Fix
MXE	Modena, PA
OOD	Woodstown, NJ
PTW	Pottstown, PA
PSB	Philipsburg, PA
PUT	Putnam, CT
PVD	Providence, RI
PWL	Pawling VORTAC
PXT	Patuxent River, MD
RBV	Robbinsville, NJ
SARDI	JFK Departure Fix
SATES	JFK Arrival Fix
SAX	Sparta, NJ
SBJ	Solberg, NJ
SBY	Salisbury, MD
SIE	Sea Isle, NJ
SLT	Slate Run, PA
SNAPY	Newark Arrival Fix
STW	Stillwater, NJ
SWEET	LaGuardia Arrival Fix
THS	St Thomas, PA
VCN	Milville, NJ

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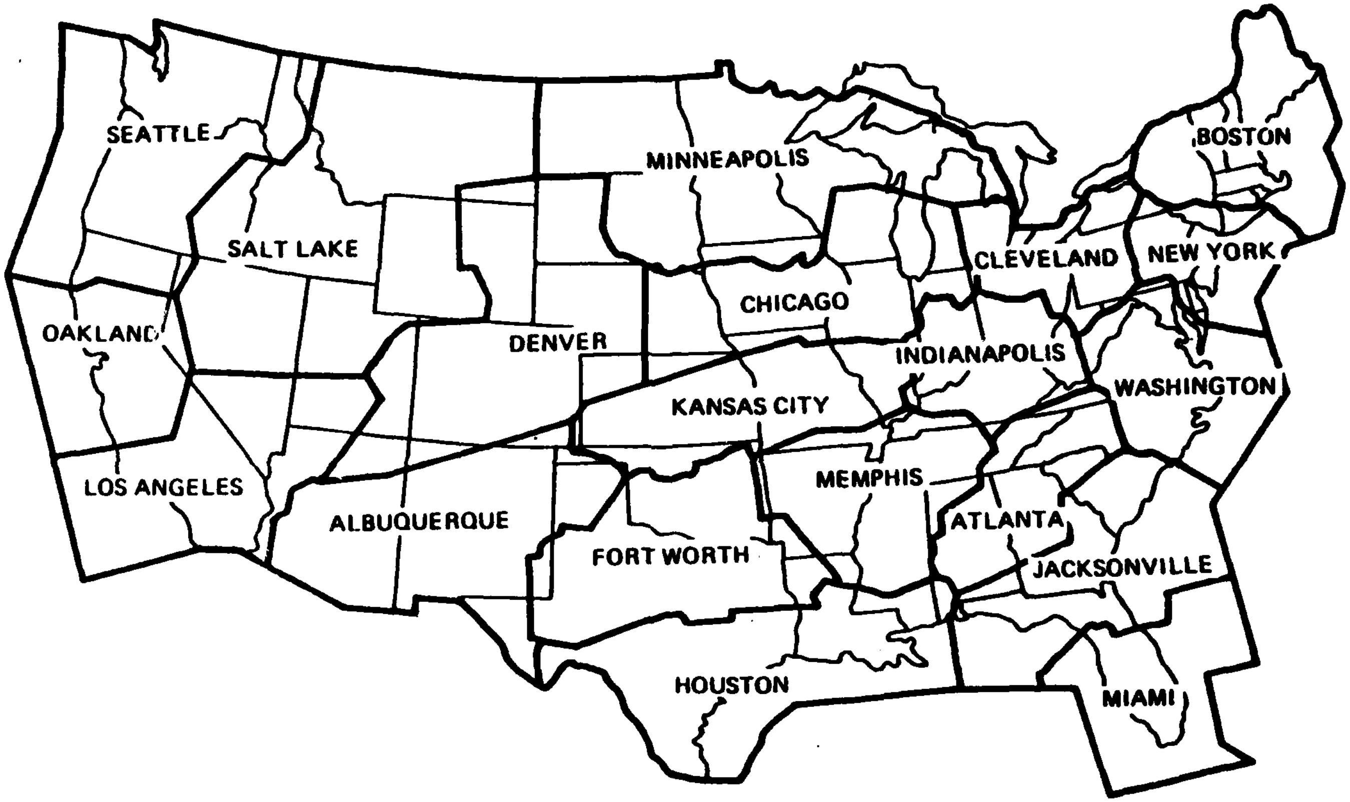

FIGURE G-4
DOMESTIC EN ROUTE LOW ALTITUDE ARTCC BOUNDARIES

For example, the Huguenot and East Texas sectors handle westbound traffic, predominately departures from New York and New England airports. The Stonyfork and Milton sectors handle eastbound traffic, predominately arrivals to New York Airports. The Harrisburg sector handles west and southwest bound traffic out of the New York area, plus Philadelphia arrivals via MIROY.J152. HAR.

2. <u>The New York high altitude flows are predominately one-way</u>: As illustrated in Figure G-2, there are very few routes in the New York Center at high altitude that are not one-way. The low altitude structure is not so restrictive except in the vicinity of the New York Metro area - see 3 below. The reason given for the preponderance of one-way routes is the fact that the majority of the traffic is transitioning in altitude within the center, so that lateral separation must be used for opposite way traffic.

3. <u>Arrival/departure routes to/from the New York Metro Area are dedicated on a per-airport basis</u>: The arrival/departure routes for the three major airports and their satellites within the NY Metro Area are illustrated in Figures G-5, G-6 and G-7. The key arrival and departure fixes are listed in Table G-3. Note that all arrival routes and some departure routes are dedicated for the exclusive use of a particular major airport and its satellites. Where these routes cross the routes for other airports, crossing altitude restrictions are procedurally imposed to ensure vertical separation between flows. The reason given for dedicating these routes to specific airports is that peak hour demands require it.

4. <u>High altitude operations to/from other than the major airports are highly constrained</u>: Flights which buck the major flows typically get less than their desired route and/or altitudes. For example, if a turbojet flight from Albany, NY (ALB) to Washington DC (DCA) wants a high altitude, it would normally be cleared via the Philipsburg PA VORTAC (PSB), on the western edge of the New York Center - see Figure G-2. This is done to put the flight outside the transitioning area for New York Metro Area arrivals and departures. The route mileage penalty is:

	Route Miles	
ALB to DCA via PSB	354	
ALB direct DCA	278	
	76	extra miles

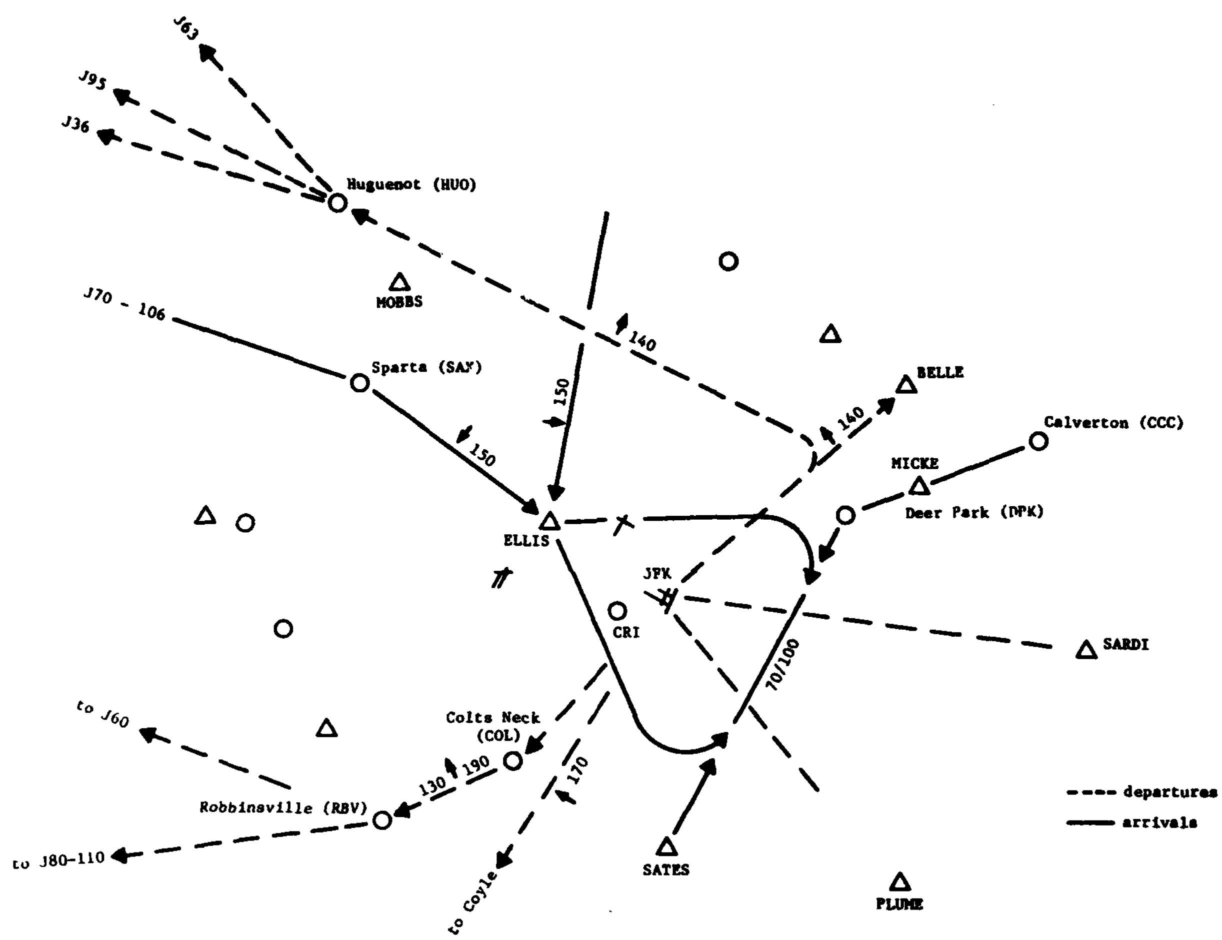

FIGURE G-5
ARRIVAL-DEPARTURE ROUTES FOR KENNEDY

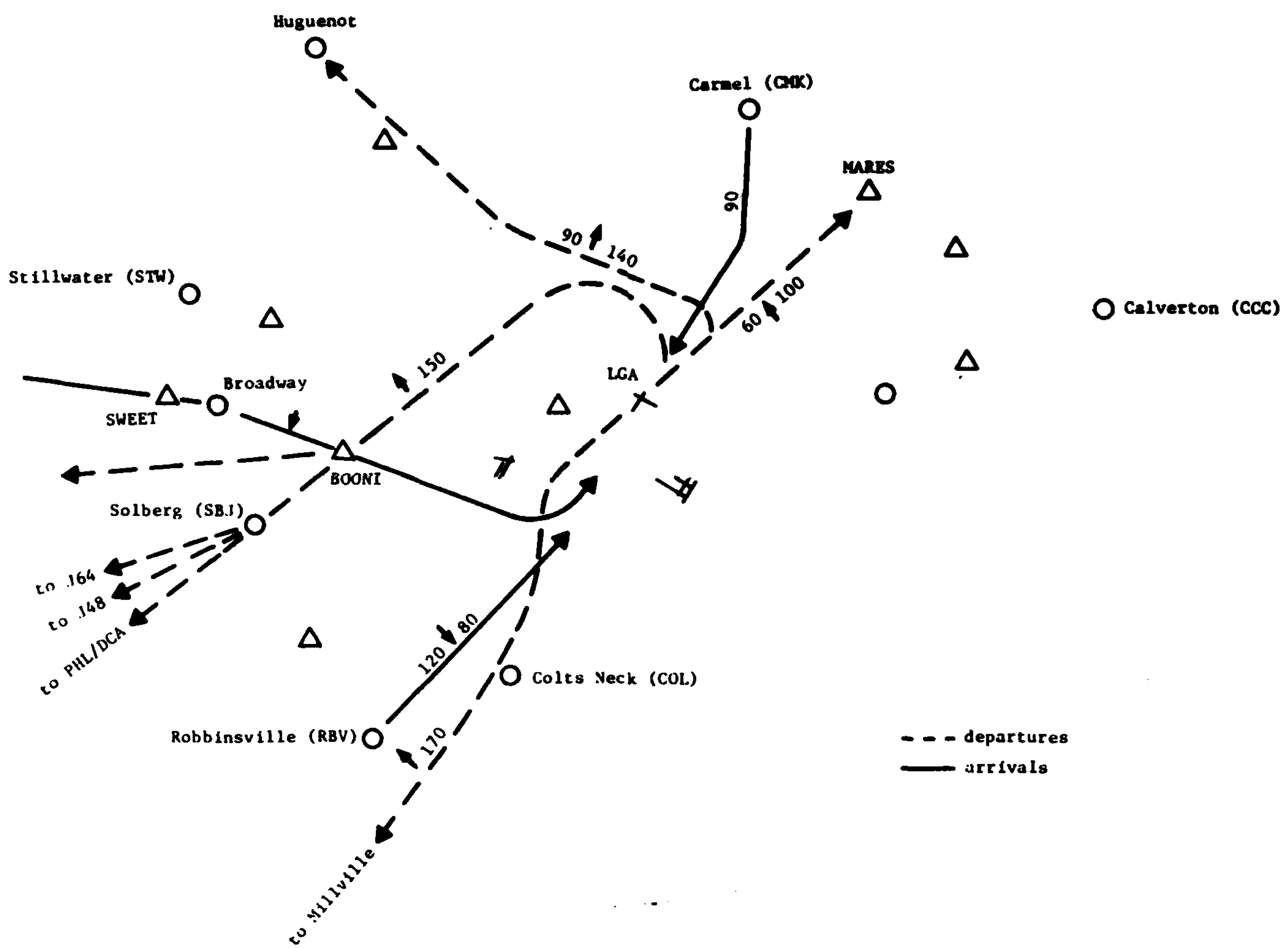

FIGURE G-6
ARRIVAL-DEPARTURE ROUTES FOR LAGUARDIA

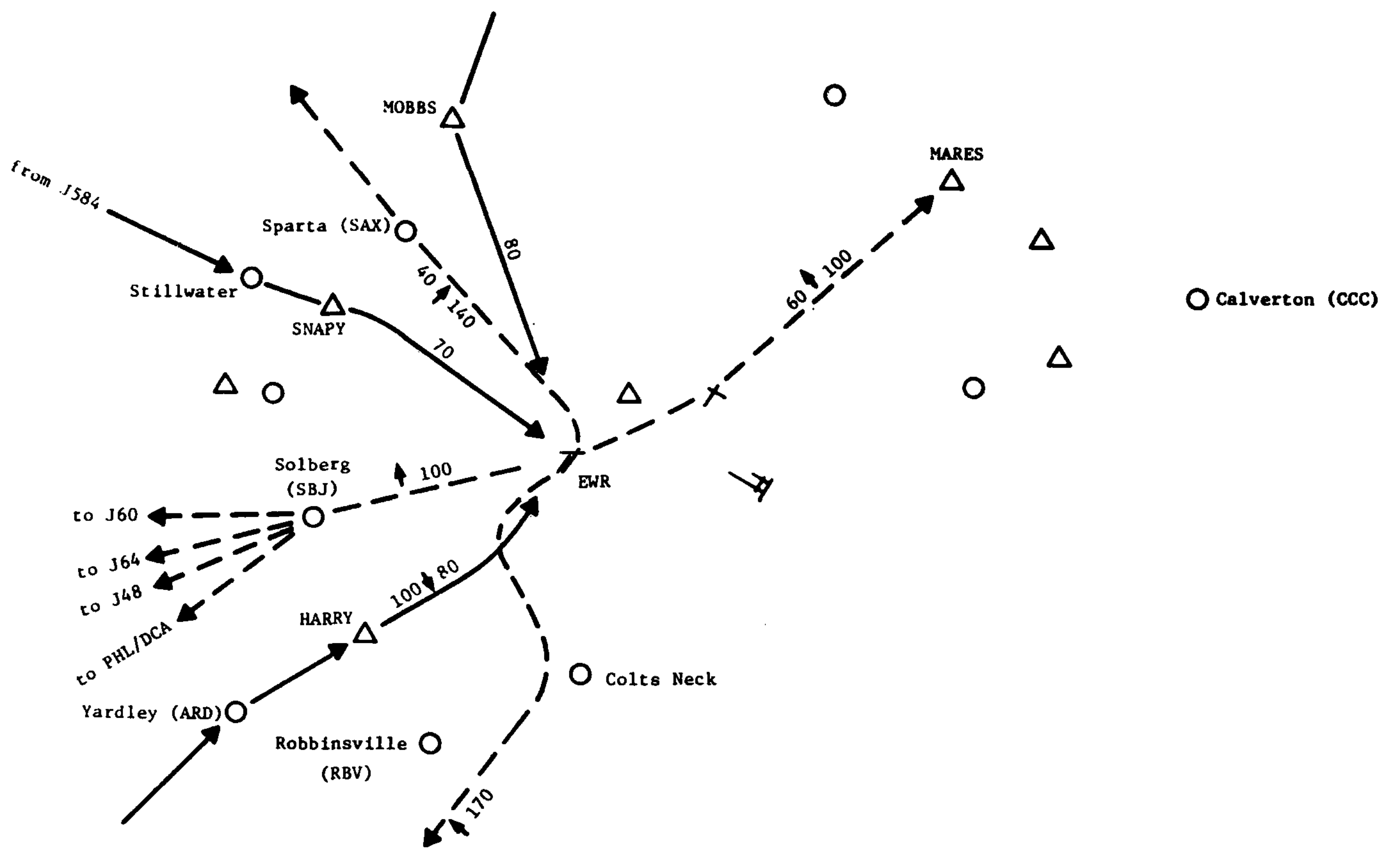

FIGURE G-7
ARRIVAL-DEPARTURE ROUTES FOR NEWARK

TABLE G-3

ARRIVAL AND DEPARTURE ROUTES FOR NEW YORK METRO AIRPORT AREAS

as of 1 December 1980

Airport Areas	Southwest thru Northwest		Northwest thru Northeast		Northeast thru Southwest	
	Arrivals	Departures	Arrivals	Departures	Arrivals	Departures
Kennedy(JFK)	HOXIE...Sparta(SAX) ...ELLIS	Huguenot(HUO)...NW/W (some SBJ...W/SW)	N(Albany)...ELLIS	BELLE...NE(Boston)	ENE(Calverton) ...MICKE SW(TWIGG or Kenton) ...Atlantic City(ACY) ...BATES	SARDI...N/NE(R57) PLUME... S/SE (A20/23)
LaGuardia(LGA)	Parkersburg(PSB) or Keating(ETG)... Milton(MIP)...SWEET	Huguenot(HUO)...NW/W Solberg(SBJ)...W/SW	...Carmel(CMK)	Mares...NE(Boston)	Woodstown(OOD)... Robbinsville	Colts Neck(COL) ...SSW(MIV)
Newark(EWR)	Slate Run(SLT) ...Stillwater(STW) ..SNAPY	Sparta(SAX)...NW/W Solberg(SBJ)...W/SW	...MOBBS	Sparta(SAX)... N(MOBBS)	Wilmington/Fatima(FYT) ...Yardley(ARD)...HARRY	Colts Neck(COL) ...SSW(MIV)

That 76 extra miles is about 27% of the direct route trip distance. That translates into a 27% fuel penalty, all other factors being equal.

Another case is that of a turbojet operator who desires to operate between Harrisburg, PA and Newark, LaGuardia, or Kennedy. Such flights are cleared to fly north until they can turn eastbound on the particular route that leads to the destination airport (J70-106 for JFK via ELLIS, or J584 for EWR via SNAPY, or J146 for LGA via SWEET). At least until the aircraft can be turned eastbound, it would be assigned to an altitude below the east-west traffic flow. In this case, the smallest route mileage penalty is:

	Route Miles	
HAR to LGA via SWEET	178	
HAR to LGA direct	148	
	30	extra miles

That 30 extra miles is about 20% of the direct route trip distance. That translates into a 20% fuel penalty, even before the fuel penalty due to the altitude restriction is taken into account.

Observation: What it would take to routinely permit more direct route operations, using the example of the Albany-to-Washington flight, was discussed with New York supervisory personnel. The functional elements of direct route probing, strategic conflict prediction, and tactical separation assurance monitoring were seen as prerequisite. These features are included in the AERA system concept (Reference 12).

G.2 Need to Coordinate More Direct Routes and Better Altitude Profiles

"Present air traffic philosophy is to minimize or eliminate coordination. This practice reduces flexibility." (NAPS Problem 18, p. 193.)

"Many procedures are designed to separate aircraft from airspace which allows the system to handle a high volume of traffic...with little or no coordination."

"During periods of light to moderate traffic, more direct routes and better altitude profiles can be achieved with additional coordination between sectors and/or facilities."

NAPS recommendation: "Emphasize system flexibility through coordination in all initial and recurrent controller training classes."

Observation: The lack of procedural flexibility is rather widespread across all en route centers. It is partly attributable to controller training and pre-strike attitudes, but it is also attributable to the current ATC system design and control decisions that are made at a supervisory level. For an example, see G.4 below.

Observation: The AERA system concept (Reference 12) provides tools for automatically doing clearance planning and coordination in a manner which treats sector boundaries as though they weren't there. Such a system would not need to impose constraints in the formulation of clearances which are not related to actual flight movements or severe weather conditions.

G.3 Inflexibility of the Dedicated Arrival Route/Fix System

Each of the three major airports in the New York Metropolitan area have their own dedicated arrival fixes and routes, as listed in Table G-3. Illustrated in Figure G-8 is the situation for those flights operating between Washington, D.C. and New York. Departure routes are designed to fit between the arrival routes.

"During certain time periods, arrival and departure demand is not in balance. At these times, departures and/or arrivals are being separated from airspace that may not be in use." (NAPS Problem 12, p. 149.)

NAPS recommendation: "... the New York Center and the New York Common IFR Room should concentrate their efforts on instituting real-time flow control actions to equalize airspace utilization..."

Observation (from Reference 3): Since NAPS, but before the controller's strike, another committee of New York ARTCC and New York TRACON specialists was established as the Review of Airspace & Metering Procedures (RAMP) committee. Its charter was to review the organization of the airspace for the New York metropolitan terminal area and the New York center. The review was triggered by these factors:

1. The recent commissioning of the New York TRACON at old Roosevelt field, and the decommissioning of the old "Common IFR Room" at JFK.

2. The coming national implementation of en route metering automation at all ARTCCs, including New York.

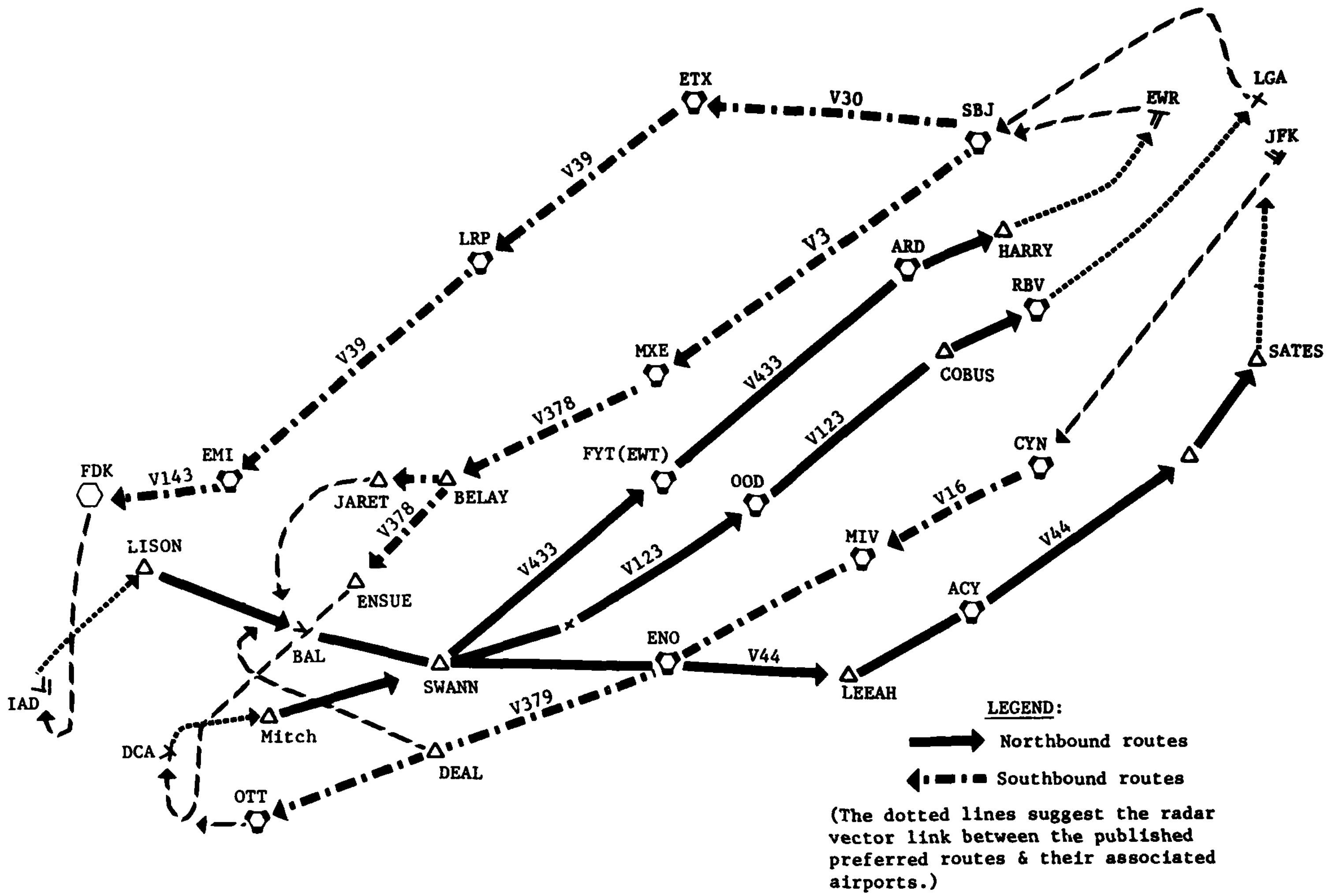

FIGURE G-8
ATC-PREFERRED ROUTE STRUCTURE BETWEEN WASHINGTON, D.C. AND NEW YORK

3. The recommendations of the NAPS committee regarding termnal area operations.

The original schedule called for a draft report in July 1981, with airspace conversions to begin by the end of the year (JFK in December; LGA/EWR 4 months later), but the aftermath of the controller's strike has temporarily suspended all further work.

The aim is to improve the throughput efficiency of this complex area. It has been observed that the old "Common I" was a common facility in name only; it operated in fact as three separate TRACON's, one for each of the three major airports, with very little airspace sharing (coordination) across boundaries.

From studying a chart covering part of the changes being considered, it appears that there would still be routes defined for each airport, but they would be relocated (departure routes were shown where currently arrival routes are, and vice versa). These possible changes are a consequence of the desire to sector the TRACON on a geographical basis, rather than on an airport basis. Presumably then, the arrival/departure routes could be used either on a dedicated or on a non-dedicated basis, depending upon the demand mix.

However, it has been pointed out that there would still be unavoidable bottlenecks in the proposed reorganization. For example, the plan is to meter to a common vertex for both Teterboro and Newark. The acceptance rate established for this vertex will be determined by the capacity of the common sector serving TEB/EWR, and not by the sum of the runway acceptance rates for TEB and EWR (the sum of the latter rates is larger than the capacity of the current sector to handle the flows).

G.4 Inflexibility of the Preferred IFR Route System

"During periods of moderate to heavy traffic, preferred routes are invaluable... in that air traffic is managed with efficiency and orderliness. However, during light traffic, the inflexibility of the preferred route system precludes the use of more direct routings even though actual traffic conditions could permit such routings." (NAPS Problem 19, p. 195.)

NAPS recommendation: "Facilities should periodically review the effective times for utilization of preferred routes and amend those times to exclude periods of known light traffic."

Observation: Table G-4 gives the effective times for the ATC "Preferred IFR Routes" which were in force though 6 August 1981

TABLE G-4

EFFECTIVE TIMES FOR ATC-PREFERRED IFR ROUTES - NEW YORK METRO AREA DEPARTURES

		Number of Published Routes			
	GMT Time: EDT Time: Daily Hours:	1000-0300 0600-2300 17	1100-0300 0700-2300 16	1200-0300 0800-2300 15	Other Shorter
Low Altitude	Newark	0	12	3	0
	Kennedy	0	10	2	0
	LaGuardia	1	11	2	0
	Westchester County	0	7	1	0
			40		
High Altitude	Newark	0	9	0	0
	Kennedy	1	33	0	0
	LaGuardia	0	9	0	0
	Westchester County	0	5	0	2
			56		
		2	96	8	2

Source: Reference 9

(Reference 9) for departures from the New York Metro Area. Note that the majority are in effect for 16 hours a day, and only 2 were in effect for fewer than 15 hours a day. These values are rather common nationally as a visual scan of Reference 9 will confirm.

While such routes are called only "preferred routes"; i.e., an airspace user can in principle file for another route which is not published, he may or may not be granted a clearance via the route of his choice. If part or all of the published "preferred route" is adapted to a given center's computer as a "preferential route" (standard departure, arrival, or departure-and-arrival route - see the more detailed discussion in Appendix A) and if that preferential route is currently active (a supervisory input), then any filed flight plan to which that active preferential route applies will be automatically amended to include it, and it will be posted accordingly. While a controller can on occasion coordinate an alternative, the computer does not assist him in that regard.

If the preferred route has not been activated, or has not been adapted as a preferential route in the computer, the controller has more flexibility in deciding whether to grant the user's request or not. However, granting the request may entail coordination with downstream sectors. Incomplete coordination can result in the kinds of problems reported in Appendix A, Section A.2, item 5. Consequently, there is a built-in bias to clear aircraft via the published and adapted preferred routes, in order to minimize coordination problems.

Observation: To the extent that demand peaks are used to justify the need for the preferred route system, it is clear to most observers that those peaks are usually short and spotty thoughout the day; the published effective times are not. Thus a routinely published "effective time" will have to cover the worst cases, ignore any demand gaps in between, and unavoidably spend alot of time protecting aircraft from otherwise empty airspace.

Observation: The AERA system has been conceived to minimize the need for such procedural restrictions. It does this by basing its clearance planning process on the proposed and actual flight movements known to it as a function of time, rather than on worst case statistics. Reducing or eliminating the need for published preferred routes is one goal sought.

G.5 Altitude Restrictions on LaGuardia Departures via Solberg

"LaGuardia-Solberg departures are restricted to 14,000 ft. until clear of the Kennedy ELLIS arrival route." See top of Figure G-9. (NAPS Problem 6, p. 57.)

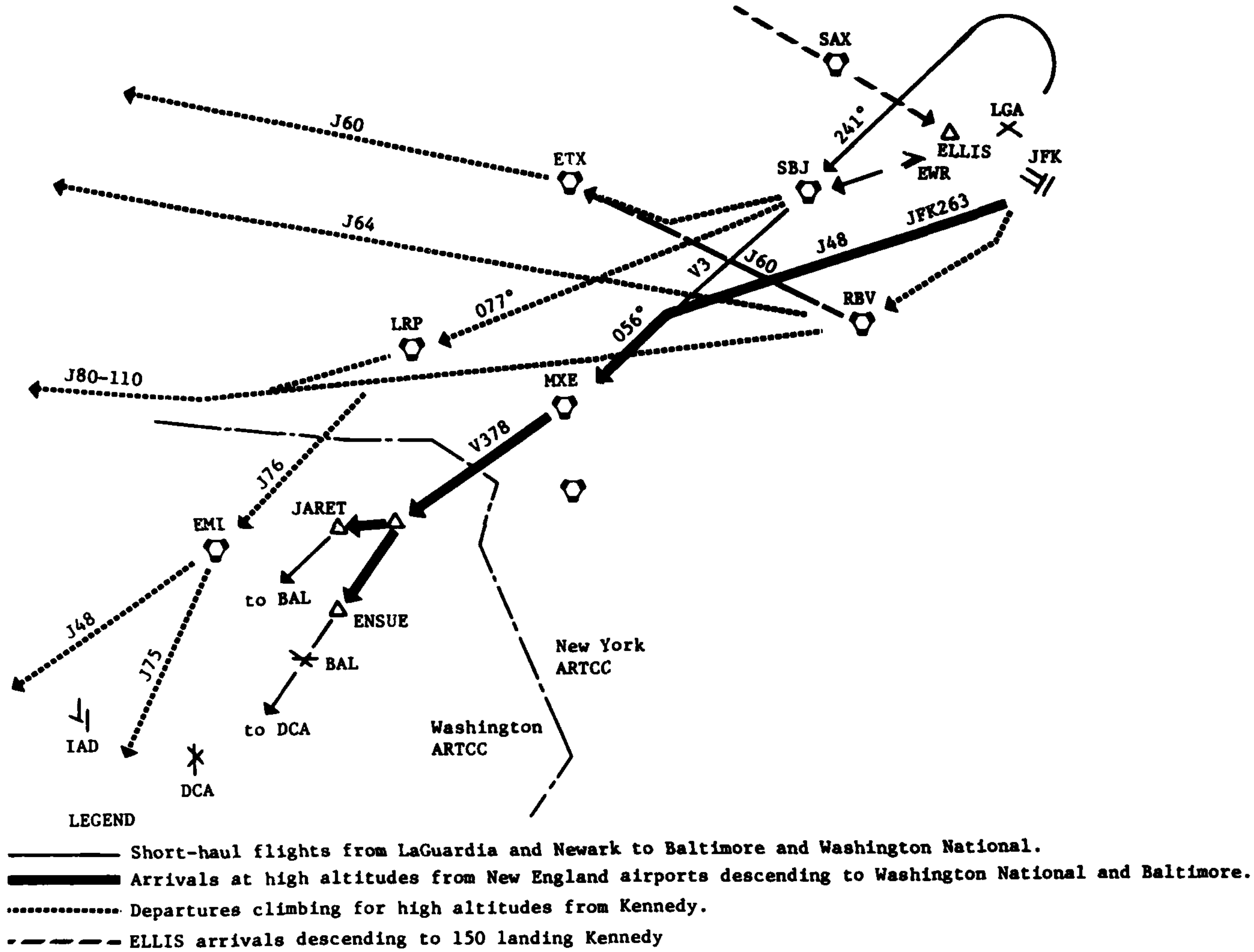

FIGURE G-9
HIGH ALTITUDE TRAFFIC CROSSING/MERGING WITH LAGUARDIA-TO-WASHINGTON FLIGHTS

If the flight were destined for the Washington Metropolitan area, it would typically be restricted to a 16,000 ft. cruise altitude. (Reference 1, Section 6).

NAPS recommendations:

1. "During periods of light traffic (0700-1300 local) especially, and at other times when possible, the ELLIS arrival sector should delegate 15,000 ft. through FL210 to the Solberg departure sector in the vicinity of the Solberg departure route (V3). The occasional ELLIS arrival during these time periods should be coordinated by the ELLIS sector with the Solberg sector. Solberg departures should be restricted to 14,000 ft. until the ELLIS arrival is cleared of V3. When the above procedure is in effect, the New York Center should advise the New York Common IFR Room. Adoption of this recommendation would allow the controller to clear Solberg departures on contact to FL200."

2. Stratify the Colts Neck High sector at FL210 and above, rather than FL180 and above. This will allow the Solberg departure at FL200 to be handed off to the Modena Low sector without coordination with the Colts Neck High sector.*

Observation: The NAPS study reports an estimated 43 gallons saved for a B727 flight between LaGuardia and Washington National,

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* Note that aircraft flying Solberg (SBJ) to Modena (MXE) leave the Solberg sector rather quickly and transit under the floor of the Colt's Neck High sector. This most easily seen by finding SBJ direct MXE in Figure G-3, recognizing that as the equivalent of the V3 southbound flow in Figure G-2, and the mentally picturing that flow relative to the high altitude sectorization map in Figure G-1.

According to the current Letter of Agreement between the Washington Center and the New York Center (Effective 7 November 1978, with revisions through 17 February 1981), "Aircraft en route to DCA/ADW via V378 shall cross the published center boundary at 22,000 feet or below and spaced in-trail." See Figure G-9.

According to controllers at the Washington Center, DCA arrivals from New York airports have recently been handed off at FL220, suggesting that the floor of Colts Neck High was actually stratified at FL230, giving the Modena Low sector FL220 and below.

relative to the previous procedural restrictions. However, as illustrated in Figure G-10, the stratification approach still imposes a ceiling altitude on all flights, regardless of their best fuel burn altitudes. For a medium weight (160 Klbs.) B727-225A on a standard temperature day, given that a normal M.80/300/250 speed schedule on descent will be used, and that the data given in Appendices B-1, B-2, and B-3 apply, the fuel burn comparisons are:

Cruise Altitude	Flight Phase	Burn Rate, Gals./N.M.	Distance, N. Miles	Fuel Burn, Gallons
280	Climb		82	677
	Cruise	3.0	31	93
	Descent		87	228
			200	998 (base)
240	Climb		60	574
	Cruise	3.3	63	208
	Descent		77	223
			200	1005 (+1%)
220	Climb		51	529
	Cruise	3.4	77	262
	Descent		72	221
			200	1012 (+1%)
200	Climb		44	486
	Cruise	3.6	89	320
	Descent		67	219
			200	1025 (+3%)

Thus, there is a fuel penalty of about 3% imposed by the recommended stratification.

This situation was first investigated by the author in 1976, when the restriction on LGA departures for DCA was 16,000 feet. Data was collected on the rates of high altitude aircraft passing over or merging with these short-hauls on the LGA...SBJ.V3.MXE...DCA route. It turned out that all of the potentially conflicting high altitude traffic was crossing on J64 or J80 or merging from J48. These results, first published in Appendix E of Reference 1, are displayed in a slightly different form in Table G-5. The top half of the

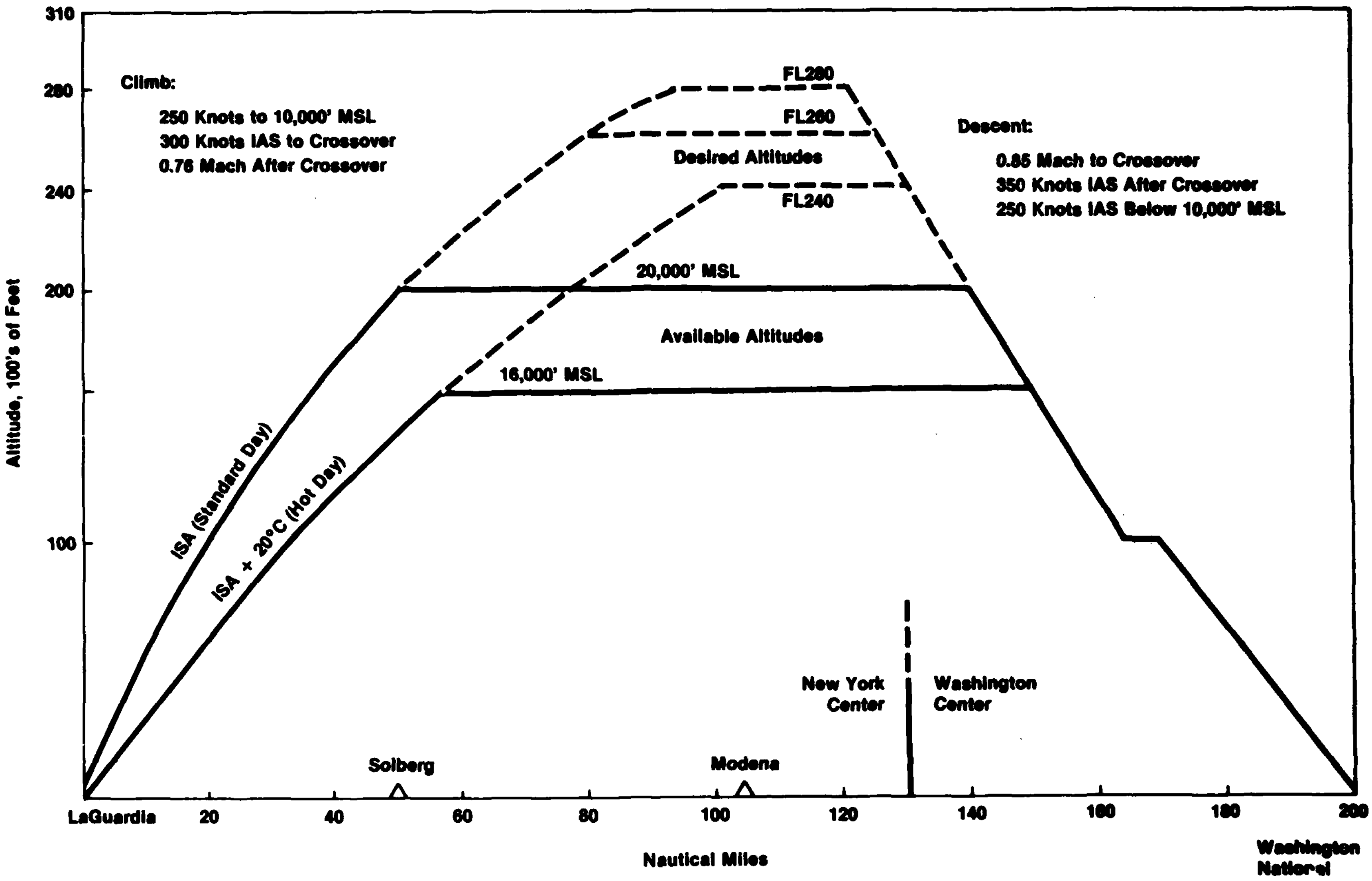


FIGURE G-10
DESIRED VERSUS AVAILABLE ALTITUDES FOR LAGUARDIA-TO-NATIONAL FLIGHTS
ASSUMES: NAPS RECOMMENDATIONS ARE IMPLEMENTED

TABLE G-5

NEW YORK TO WASHINGTON DC SHORT HAULS VS. OTHER HIGH ALTITUDE TRAFFIC

	Route	Type of Flight	Altitude Profile, 100s of Feet	Number of Aircraft Observed Over V3 Each Hour[1] 0730 thru 1230 EDT					Hourly Average
High Altitude Traffic Crossing or Merging With New York to Washington, DC Short Hauls	J64	JFK Departures for Chicago and Points West	350 or 390 Requested or Assigned 200 to 290 Reported crossing V3	0	1	1	1	1	1
	J80	JFK and LGA Departures for Nashville and Points Southwest	310 or 350 Requested or Assigned 220 to 300 Reported crossing V3	4	3	4	4	2	3
				$\overline{5}$	$\overline{4}$	$\overline{5}$	$\overline{5}$	$\overline{3}$	$\overline{4}$
	J48	DCA and BAL Arrivals from Boston and Points North	Requested unknown (350 appropriate) 220 Assigned 220 Reported joining SBJ..MXE	(2)	(2)	(2)	(2)	(2)	(2)
		(B727, L1011, B727, DC9, ..)							
New York to Washington Short Hauls (Turbojets Only)	SBJ..MXE (V3)	LGA Departures for DCA/BAL (B727, DC9, LR24)	Requested unknown (240 to 280 appropriate) 140 or 160 Assigned 140 or 160 Reported	2	1	2	0	3	1+
		EWR Departures for DCA/BAL (B727 or DC9)	Requested unknown (240 to 280 appropriate) 160 Assigned 90 to 110 Reported crossing SBJ	0	3	0	1	0	1-
		HPN/MMU Departures for DCA/BAL	Requested unknown (240 to 280 appropriate) 120, 140, or 160 Assigned	1	2	1	0	0	1-
		(DC9, BA11, FFJ)	90 to 160 Reported crossing SBJ	3	6	3	1	3	3

Notes

1. Observations made by the author on Friday, 23 July 1976 from 0730 to 1230 EDT. (Reference 1)

table shows potentially conflicting high altitude flights, their altitudes crossing SBJ.V3.MXE, and the number of flights observed each hour. The bottom half shows the number of turbojets observed flying from LGA to DCA via MXE. The observations were made continuously over a 5 hour period on a busy Friday morning from 7:30 am to 12:30 pm, EDT.

The tabulated data shows that not more than 5 crossing flights, and not more than 2 merging flights, were observed during any hour. Since the merging flights must be merged for descent into DCA and BAL, regardless of the altitudes assigned to the short-hauls, the only additional conflicts that need to be considered are those that might be produced if the stratification restriction at 16,000 feet then, and at FL200 or FL220 now, were removed. At 5 crossing flights per hour, and assuming that each crossing aircraft occupies the intersection for two minutes (12 miles route width x 6 miles per minute = 2 minutes to cross), only during 10 minutes out of each hour could one expect that a crossing conflict to be present.

Said another way, the odds are 5 to 1 that no crossing conflict will be present when a given departure from LGA for DCA or BAL requests a cruise altitude assignment. Based on the fuel analysis above, it is likely that the departure would prefer an altitude assignment above the current restriction of FL200 or FL220.

The question then is: What would it take to dynamically coordinate the use of the preferred altitudes in this region between these southbound departures from LGA and these westbound departures from JFK? The answer would very well be a conflict probe of the type illustrated in Figure 5-2 of The AERA Concept (Reference 12).

G.6 Circuitous Routes and Restricted Altitudes for Other Short Haul Flights

"Boston and New York Center sectors are divided into high altitude sectors and low altitude sectors. The majority of low altitude sectors in both centers control traffic at 17,000 feet and below. The majority of high altitude sectors control traffic at FL 180 and above. Due to the proximity of certain airports to center boundaries, "short haul" flights are often restricted to cross these boundaries at 17,000 feet or below. These restrictions eliminate coordination with high altitude sectors on both sides of the boundary and reduce short duration frequency changes for pilots." (NAPS Problem 7, p. 65.)

"Initial stratification of high and low sectors was made in the early 1960's paralleling the beginning of the commerical 'jet age'. Many aircraft did, at that time and many years subsequent thereto, flight plan for FL 180 through FL 230. Today's aircraft are cruising at higher altitudes. There is, in fact, underutilization of the airspace between FL180 and FL230 except for transitioning traffic." (Both p. 65 & 66.)

NAPS recommendations:

1. Raise the ceiling of low altitude sectors along the New York Center's boundaries with the Boston, Cleveland, and Washington Centers. Specific recommendations were made - see the column entitled "Highest Available [Altitude] After NAPS" in Table G-6.

2. "Both New York and Boston Centers should re-examine the stratification of low altitude sectors which do not abut their common boundary for possible adjustment and standardization."

Observation: Center boundary crossing restrictions on short-haul flights nearly always become de facto cruise altitude restrictions on those flights. Based on this assumption, the right-hand side of Table G-6 compares the:

Nominal Altitude Desired if the user were flying a typical mid-weight turbojet on a standard temperature day, with the

Highest Available Altitude at the center boundary procedurally admitted, both before NAPS and After NAPS recommendations are considered.

Since in nearly every case, the highest available altitude after NAPS is still lower then the altitude assumed to be desired by the turbojet operator, the next column provides the estimated fuel penalty, based on the altitude differential and the estimated cruise miles flown at the lower altitude. The fuel penalties due to the altitude restrictions for those short-haul routes (which are between 250 and 400 n. miles in length) range from zero to 10% of of the total trip fuel burn.

Observation: As noted previously for the ALB-DCA, HAR-LGA, and HAR-EWR examples, short-haul turbojets also must conform to the predominate high altitude traffic flows. Consequently they often fly something other than a direct route to their destinations. Some other examples taken from Table G-6 are illustrated in Figure G-11. The extra route miles impose an additional fuel penalty which runs as high as 19% in the table, and as high as 27% in the examples previously cited.

TABLE G-6

SOME ROUTE AND ALTITUDE RESTRICTIONS IMPOSED ON SHORT HAUL FLIGHTS

Based on NAPS Problem 7, Restrictions at Center Boundaries

		Approximate En Route Miles (n.m.)[1]			Cruise Altitude Between City Pairs (100's of Feet or FL)				
From:	To:	Direct Route	Available Route After NAPS[3]	Estimated Mileage Penalty[2,3,4] (% of NAPS Route)	Nominal Altitude Desired[5]	Highest Available at Center Boundary Before NAPS	Highest Available at Center Boundary After NAPS	Estimated Altitude Penalty[2]	Estimated Fuel Penalty[6] (% of Total Burn for Trip Distance betw. 250 & 400 N. miles)
Boston	LaGuardia	160	183	23(14%)	220	160	200	20	12
LaGuardia	Boston	160	175	15(9%)	230	190	210	20	12
Boston	Newark	174	205	31(18%)	240	160	160	80	55
Newark	Boston	174	189	15(9%)	230	190	210	20	13
Boston	Kennedy	(not examined)				(not examined)			
Kennedy	Boston	160	170	-	230	190	210	20	12
Albany	LaGuardia	120	130	-	200	160	200	none	none
LaGuardia	Albany	(not examined)				(not examined)			
Albany	Newark	120	130	-	200	160	160	40	17
Newark	Albany	(not examined)				(not examined)			
Syracuse	LaGuardia	172	200	28(16%)	230	170	190	40	27
LaGuardia	Syracuse	172	182	-	240	160	200	40	24
Syracuse	Newark	(not examined)				(not examined)			
Newark	Syracuse	172	182	-	240	160	200	40	24
Syracuse	Kennedy	180	190	-	230	170	190	40	25
Kennedy	Syracuse	180	210	30(17%)	240	160	200	40	28

TABLE G-6

(Cont'd)

Syracuse	Philadelphia	195	212	17(9%)	230	170	190	40	28
Philadelphia	Syracuse		(not examined)						
Buffalo	Boston		(not examined)			(not examined)			
Boston	Buffalo	344	354	-	310	220	220	90	117(8%)
Buffalo	NY airports		(not examined)			(not examined)			
NY airports	Buffalo								
Pittsburg	Albany	320	(not known)		290	170	190	100	148(10%)
Albany	Pittsburg	320	362	42(13%)	310	220	310	0 (Non-Busy Hours)	none
					310	220	220	90 (Busy Hours)	96(7%)
Pittsburg	Boston	421	(not examined)			(not examined)			
Boston	Pittsburg	421	475	54(13%)	310	220	310	0 (Non-Busy Hours)	none
					310	220	220	90 (Busy Hours)	(Note 7)
Pittsburg	Providence	394	(see Pittsburg/Boston above)						
Providence	Pittsburg	394							
Pittsburg	LaGuardia		(not examined)						
LaGuardia	Pittsburg	278	304	26(9%)	310	220	310	0 (Non-Busy Hours)	none
					310	220	220	90 (Busy Hours)	87(7%)
Pittsburg	Newark		(see Pittsburg/LaGuardia above)						
Newark	Pittsburg								
Pittsburg	Philadelphia	233	(not examined)			(not examined)			
Philadelphia	Pittsburg	233	(not examined)		240	220	310	0 (Non-Busy Hours)	
					240	220	220	20 (Busy Hours)	16
Philadelphia	from southwest terminals via Martinsburg (MRB):								
Mileage from MRB		126	150	24(19%)	250 - 290	210 (at center boundary)	250	0 to 40	10

TABLE G-6

(Concl'd)

Washington, D.C.	New York Area	(see Figure from Reference 1)	(see Table from Reference I)
New York Area	Washington, D.C.		

Notes:

1. Does not include extra flying miles on departure or arrival within terminal areas needed between the active runway and the beginning or the end of the most direct available route between city pairs.

2. Assumes that any route or altitude improvements recommended by NAPS have been implemented.

3. If the extra miles appeared to be less than 10, the available miles and extra miles were not computed.

4. Mileage penalty as a percentage of the direct route is shown in parentheses.

5. Assumes a 160 Klbs. B727-225A on a standard (ISA) day flying the available route distance.

6. Assumption: Center boundary crossing restrictions on short-haul flights nearly always become de facto cruise altitude crossing restrictions. For the purpose of this analysis, short-hauls are considered to be flights of less than 400 n.m.

For trip distances of less than 250 n. miles, the analysis assumes fuel penalty per mile for flying at an altitude different than the fuel optimal altitude is 0.1 gallon per 1000 feet of difference. It also assumes that the distance flown at that altitude is 1/3 of the available route distance. For trip distances of more than 250 n. miles, fuel burns for each case were individually calculated using available performance data for a 160 Klbs. B727-225A. Note that in all cases, the fuel penalty due to extra route miles is not included.

7. Since the trip distance is more than 400 n.m., the assumption made in 6. does not apply, and no fuel penalty due to this altitude restriction is estimated.

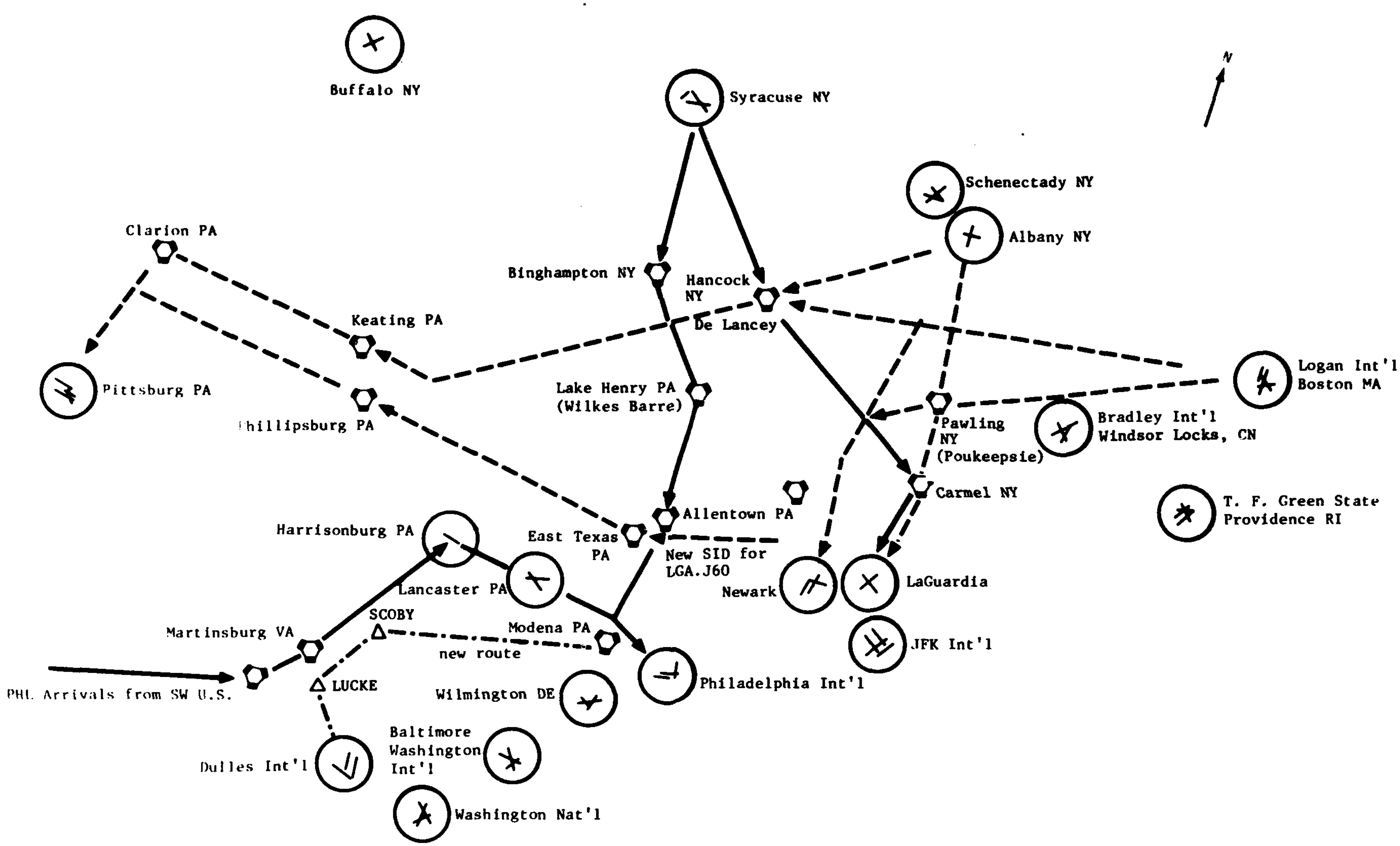


FIGURE G-11
SOME ATC-PREFERRED ROUTES FOR SHORT HAUL FLIGHTS

G.7 Circuitous Routes and Restricted Altitudes for Low Altitude Enroute Aircraft

"Terminal complexities, geographical constraints, and increased traffic demand diminishes the capacity of the terminal air traffic system to handle enroute traffic. This condition results in degraded service to users requesting to transit the New York and Boston Metropolitan areas in the low altitude structure." (NAPS Problem 21, p. 201.)

NAPS recommendations:

1. "Expanded use of the "northeast-southwest low level route" by adding northbound aircraft destined for airports on Long Island within Westchester approach control's "East Sector" or for New England airports beyond Windsor Locks, and by adding southbound aircraft destined for the Philadelphia/McGuire, Atlantic City, or the Washington Center areas."

This route is defined as V16 at 6,000 ft. MSL for southbound flights between Deer Park, L.I., and Coyle, N.J., overflying JFK, and as V229 at 7,000 ft. MSL for northbound flights between Atlantic City and Windsor Locks, also overflying JFK. All higher altitudes are procedurally reserved for other traffic. There are no other routes defined for IFR overflights which penetrate the New York TCA.

2. "Add another low-level north-south route which circles around the west edge of the New York TCA via Robbinsville (RBV), Solberg (SBJ), Broadway (BWZ), and Sparta (SAX)". This route would serve northbound aircraft destined for airports within the Westchester approach control's "West Sector" or the Catskill area, and would serve southbound aircraft destined for airports within the Philadelphia/McGuire area.

Observation: This route is approximately 51 miles shorter than the previous route: Pawling V93 Lake Henry V149 MAZIE, but it still is much longer than a direct route to any of these airports since it still requires circumnavigation of the New York TCA.

3. "Establish east-west routes (one for each way) for any type aircraft to/from airports on Long Island and airports north of V232 within the Newark sector" (e.g., Morristown Muni, Essex County, Teterboro.). Routes recommended are approximately 35 miles shorter than going via Colts Neck, N.J. (the old route), but still are not direct. Aircraft to/from airports south of V232 within the Newark sector (e.g., Linden, Somerset Hills, N.J.) would still circumnavigate the TCA to the south via Colts Neck.

Observation: It is unfortunate that rigid routes must be established for slow speed, low altitude traffic in order to separate it from higher performance aircraft which may be operating to/from New York Metro Area airports. In the AERA system concept, the idea is to minimize the need for such procedural restrictions by (1) more accurate prediction and coordination of user-proposed flight movements and by (2) automated monitoring and control of these movements. In theory at least, such an approach allows the airspace to be time-shared between actual users, rather than being carved up into dedicated traffic flow channels, whose restrictions are applied whether or not those channels are currently being used by other aircraft.

G.8 Circuitous Routings for JFK Arrivals from the West and Northwest

"Kennedy arrival traffic via ELLIS experiences lengthy and circuitous vectors." See Figure G-12, G-13, and G-14. (NAPS Problem 17, p. 177.)

Because of the present system's need to segregate arrival and departure flows, and because the LGA and EWR airports are just west of JFK, there is no airspace remaining below 15,000 ft. MSL from which to define more direct approach routes into JFK from the west and northwest. Consequently, all such arrivals must overfly EWR and LGA at 15,000 ft. MSL, make at least 2 turns, and return to JFK from the east - see table below.

APPROACH ROUTES TO KENNEDY AIRPORT

		Miles from ELLIS to Runway*		
Landing to:	Number of 90° Turns Past ELLIS	Now, Heavy Demand	Now, Light Demand	Possible, if Route is Coordinated
SE (13 L/R)	4	80	55	45
NE (4 L/R)	3	74	49	39
NW (31 L/R)	2	56	46	37
SW (22 L/R)	3	71	55	47

*ELLIS is 15 DME miles from the JFK VOR.

NAPS recommendation: "During periods of light to moderate traffic..., the CIFRR should continue to make every effort to coordinate, internally, with a view towards shortening the vector route..."

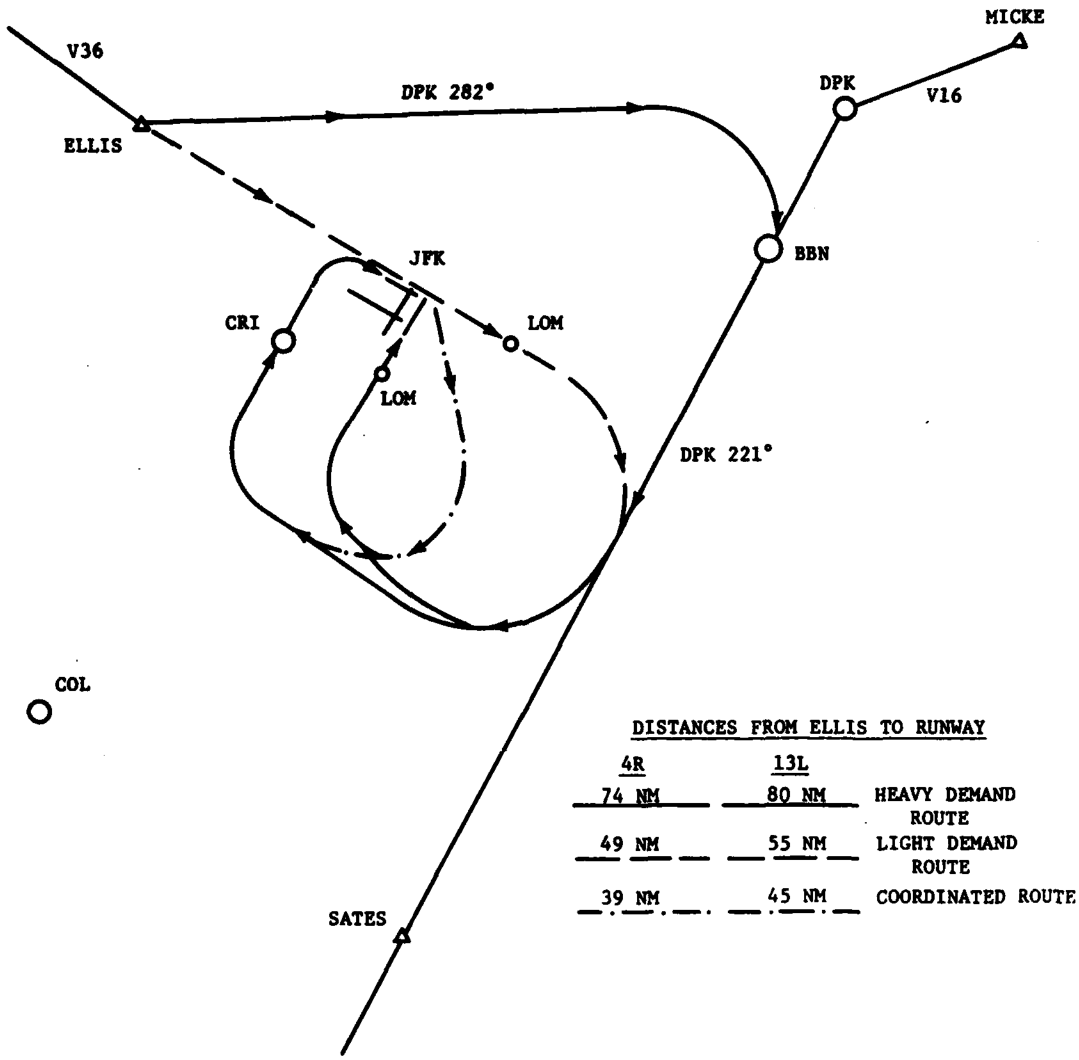


FIGURE G-12
JFK RUNWAY 4R ILS/CRI VOR ARRIVAL FLOW FROM ELLIS

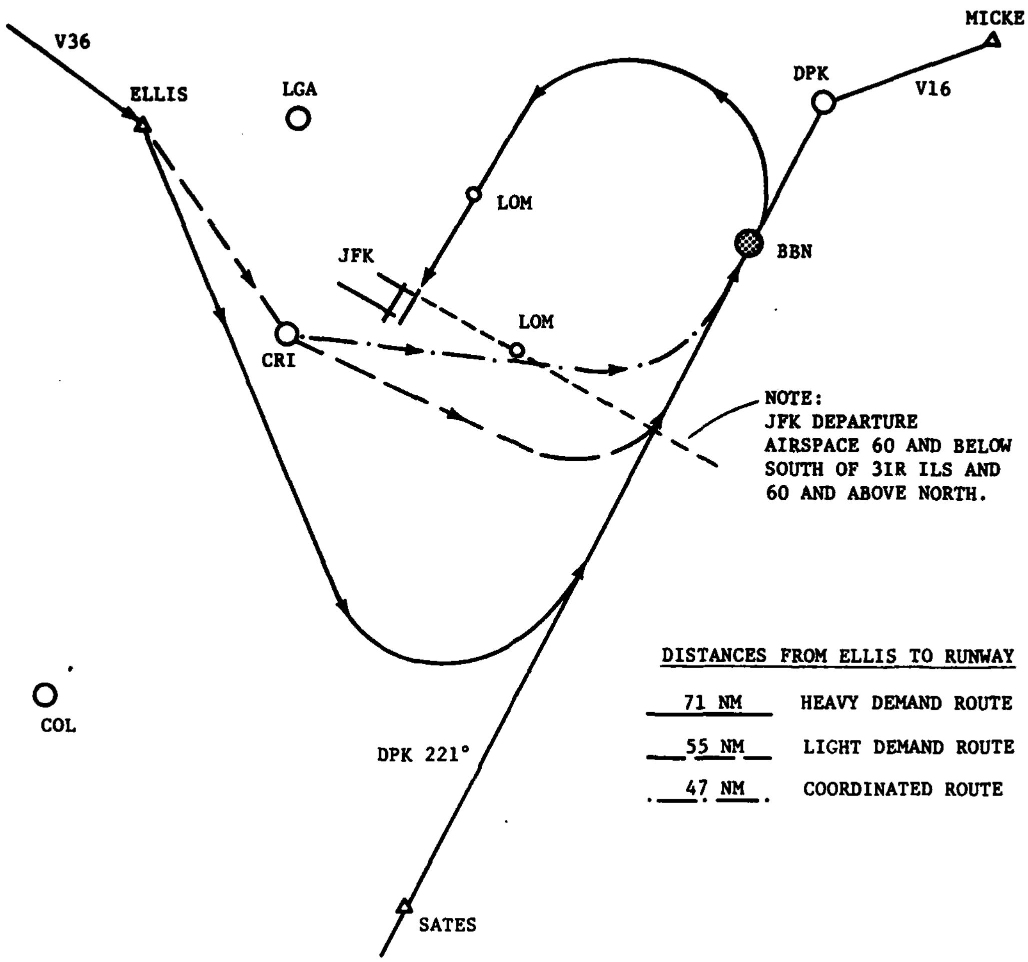


FIGURE G-13
JFK RUNWAY 22 ILS ARRIVAL FLOW FROM ELLIS

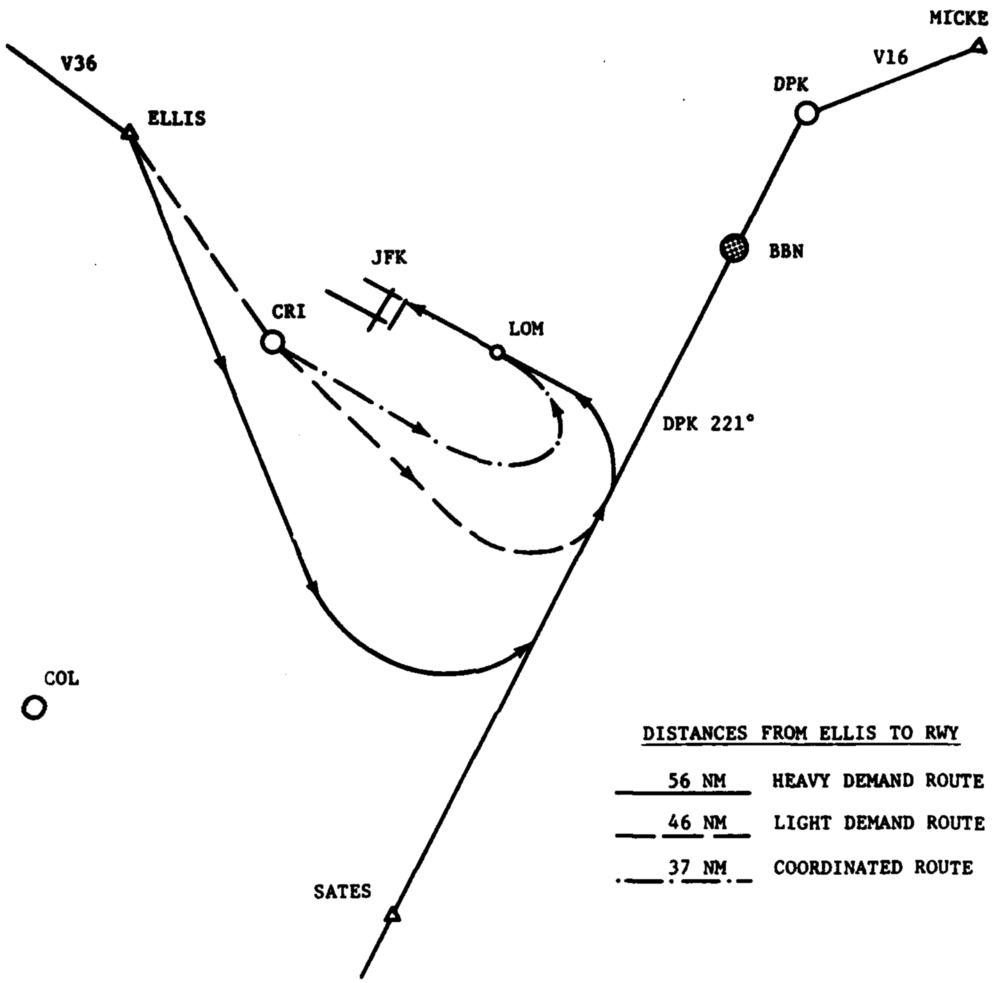


FIGURE G-14
JFK RUNWAY 31 ILS FLOW FROM ELLIS

Note: The committee attempted to relocate ELLIS but found that, given present constraints, it could not without unacceptable impacts elsewhere.

Observation: It is unfortunate that aircraft within 15 DME miles of JFK still have 37 to 80 miles to fly, exclusive of any delaying maneuvers for sequencing and spacing. The extent to which the airspace time-sharing philosophy of the AERA concept can be applied to the New York Metro Area complex is unknown at this time. However, if it should prove successful in less busy airspaces, extensions of it to the busier airspaces are probably worth investigating.

G.9 Altitude Restriction on Caribbean Arrivals to Newark

"Arrival aircraft from the Caribbean are cleared to 3,000 feet for extended periods when landing the Newark area." This requires flight at 3,000 feet for 45 to 90 miles, depending upon the runway in use. See Figure G-15. "In addition to the fuel inefficiency involved, users are concerned with their exposure to VFR traffic..." (NAPS Problem 9, p. 121.)

NAPS recommendations:

1. "Users should analyze the benefits of flight planning to Newark via Sea Isle to minimize exposure to VFR aircraft..." "This route is 65 miles longer, but allows aircraft to cross 28 miles southeast of Sea Isle at cruising altitude."

Observation: A 65 mile route penalty for an aircraft that burns several gallons of fuel per mile is rather significant at today's prices. At 2.9 gallons per mile, this adds 190 extra gallons to the total trip fuel burn. Assume an otherwise unrestricted flight from San Juan to Newark in a mid-weight B727-225A on a standard day:

	Distance (n.m.)	Fuel Burned (gals.)
Climb to 350	128	869
Cruise at 350	1279	3709
Descend from 350	93	244
Total for Trip:	1500 n.m.	4822 gals.

That 190 extra gallons represents a 4% increase in total trip fuel burn.

2. "A TCA extension should be developed at altitudes from 3,000 feet..." to protect those arrivals using the existing route.

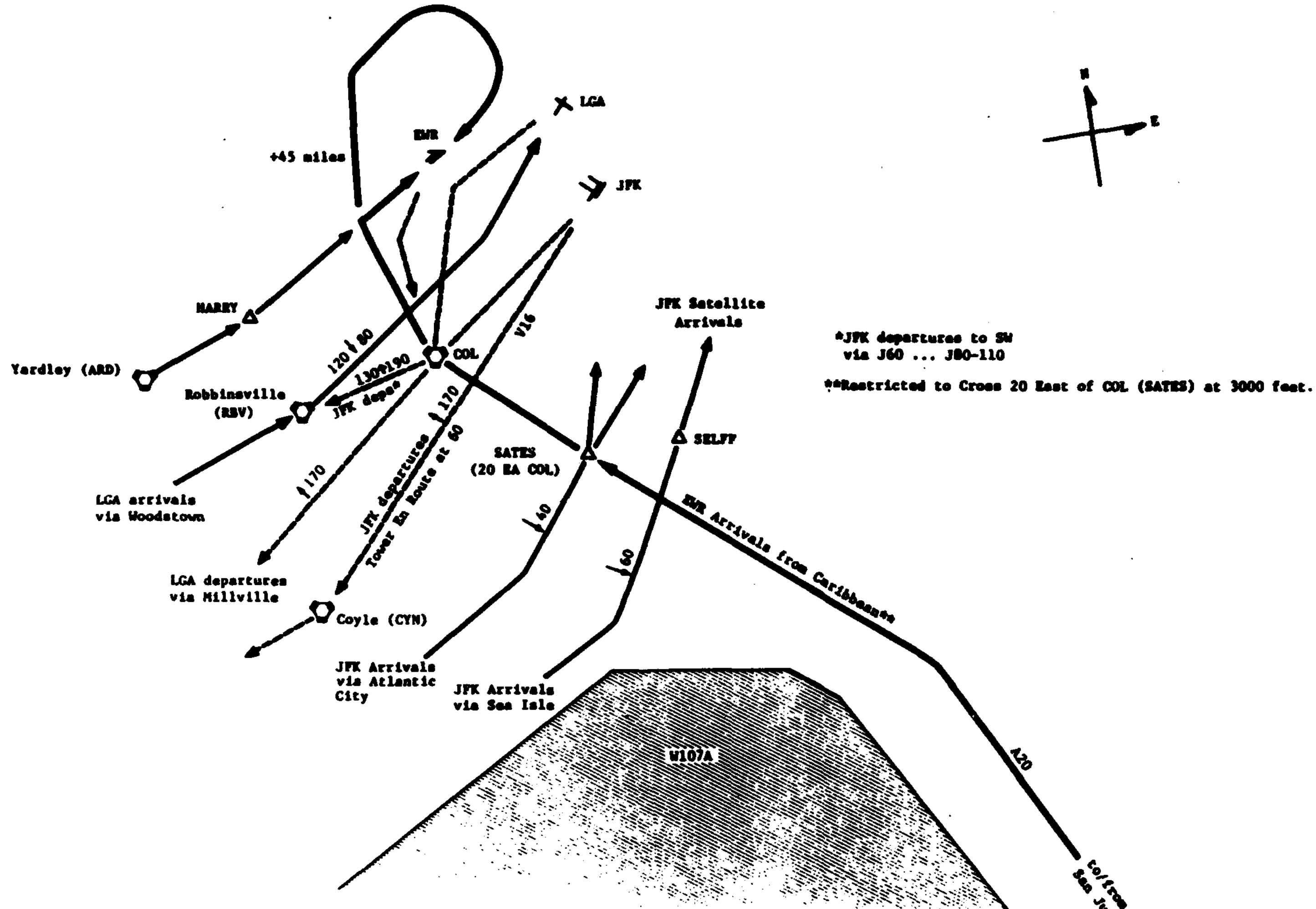


FIGURE G-15
REASON FOR THE ALTITUDE RESTRICTION ON NEWARK ARRIVALS FROM THE CARIBBEAN

Observation: Compare the above with the desired altitude for the aircraft - see Figure G-16:

Distance to Runway	Desired Altitude	Restriction at 20 n.m. East of Colts Neck: Before NAPS	After NAPS	Estimated Fuel Penalty
37	12,000 ft.	3,000 ft.	3,000 ft.	85 gals.
82	33,000 ft.	3,000 ft.	3,000 ft.	190 gals

For the San Juan to Newark flight above, that 85 to 190 extra gallons represents a 2% to a 4% increase in total trip fuel burn.

3. "When runway 22 is in use at Newark, the New York Common IFR Room should coordinate internally to vector the Caribbean arrival via Colts Neck east of Newark for a left turn in. This vector would shorten the flight path by 40 miles."

G.10 Altitude Restriction on Caribbean Arrivals to Kennedy

"Traffic proceeding from the Caribbean into the New York Metropolitan area is routinely issued a restriction to cross 55 miles southeast of the Kennedy VORTAC at 10,000 feet, which results in fuel inefficiency." See Figure G-17. (NAPS Problem 1, p. 21.)

This restriction is used to (1) "...integrate this traffic with aircraft enroute to SATES arrival fix from the south...", and (2) to ensure "... separation with Philadelphia/McGuire arrivals which are southbound on J121/V139, cleared to descend and cross DRIFT intersection at 8,000 feet. The Kennedy arrivals are descended to cross V139 at 7,000 feet or below." At this point, they are about 38 DME miles from JFK and anywhere from 40 to 80 flying miles from the runway threshold.

NAPS recommendation: Raise the restriction by 2,000 feet on both the Caribbean arrivals and the Philadelphia/McGuire arrivals.

Observation: Compare the above with the desired altitude for the aircraft:

Distance to Runway	Desired Altitude	Altitude 55 SE JFK Before NAPS	After NAPS	Estimated Fuel Penalty
55 n.m.	17,000 ft.	10,000 ft.	12,000 ft.	19 gals.
87 n.m.	31,000 ft.	10,000 ft.	12,000 ft.	82 gals.

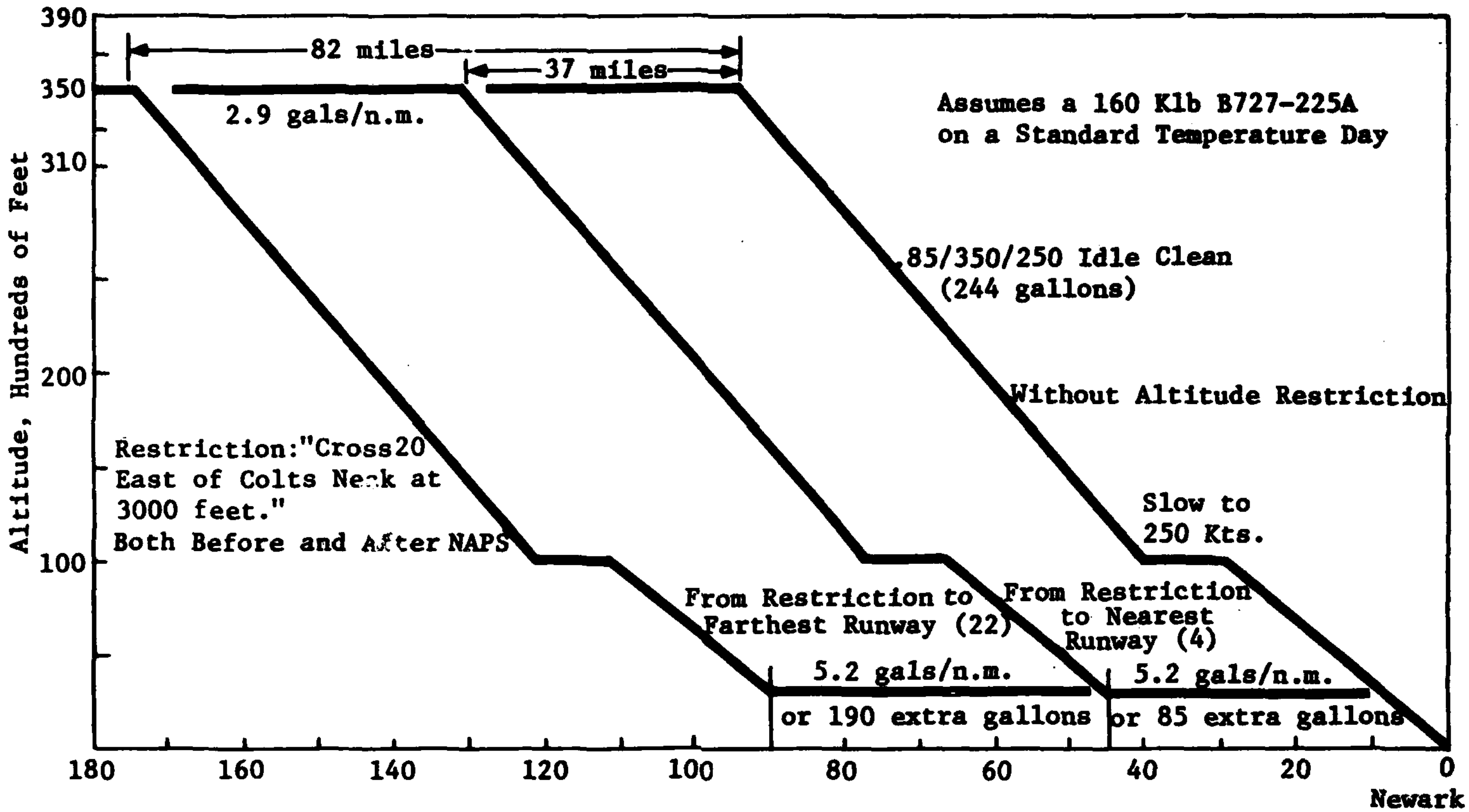


FIGURE G-16
FUEL PENALTY DUE TO EARLY DESCENTS FOR NEWARK ARRIVALS
FROM THE CARIBBEAN

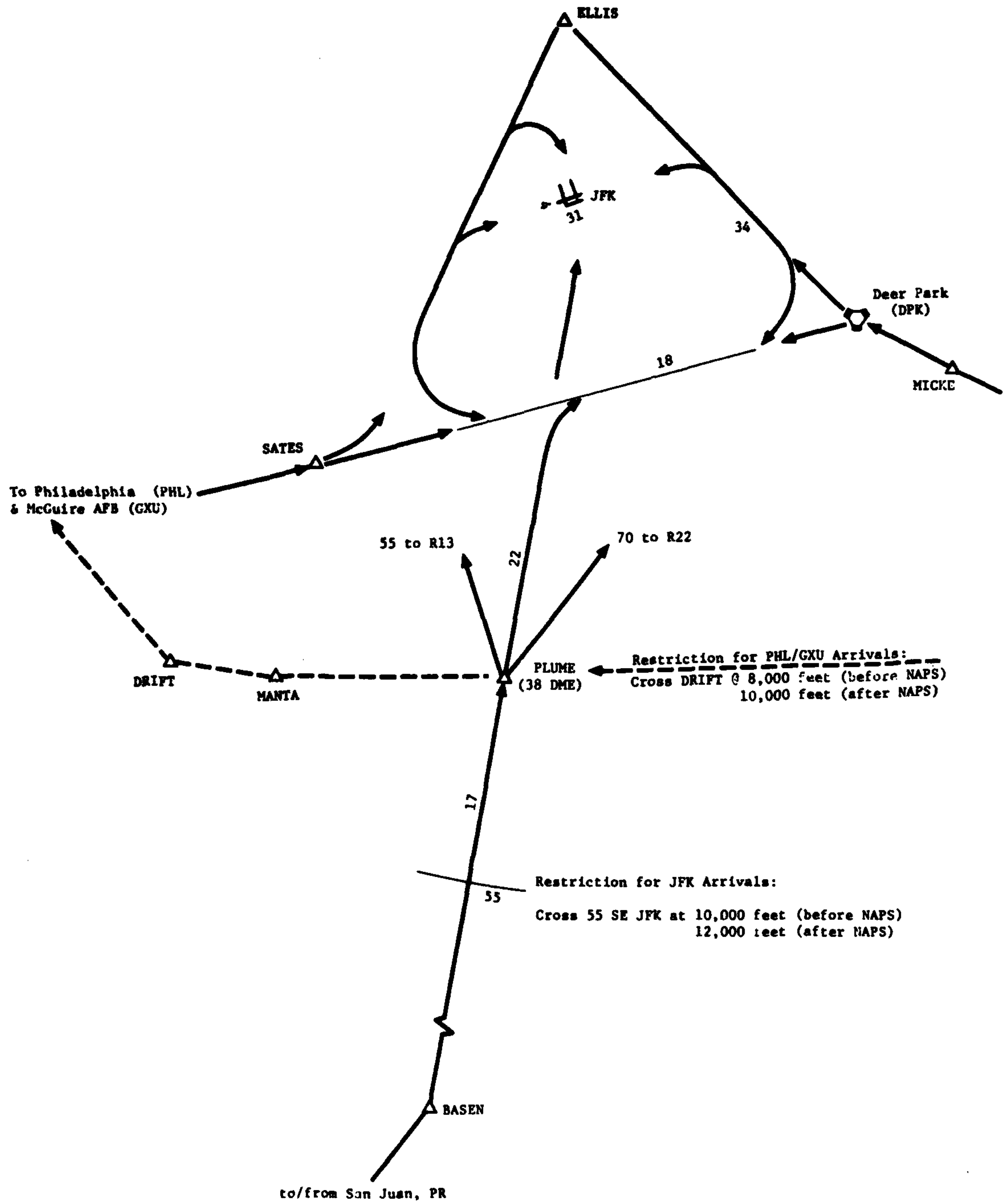


FIGURE G-17
REASON FOR THE ALTITUDE RESTRICTION ON KENNEDY ARRIVALS FROM THE CARIBBEAN

For the San Juan to Newark flight, that 19 to 82 extra gallons represents an averaged 1% increase in the total trip fuel burn.

G.11 Delays in Satisfying Pilot Requests for a Change in Over-Ocean Altitude or Route

Delays in getting a revised ATC clearance can run "as much as 15 to 20 minutes in some cases". Such delays are attributed to "... the actions necessary prior to a controller being able to approve or deny a pilot request for a change in altitude or route. This is especially true for flights tranversing the North Atlantic."

"Manual prediction and manual coordination are the direct causes of delayed responses to pilot requests. (NAPS Problem 32, p. 261.)

For North Atlantic flights, " the controller must project the flight through the New York Oceanic area checking for potential conflicts in a non-radar environment and then coordinate with Canadian ATC facilities, who must also check for conflicts prior to approval. This process applies equally to Caribbean or South Atlantic traffic where coordination must be accomplished with Santa Monica, San Juan, and/or Bermuda ATC."

NAPS recommendation: "The Eastern Region should initiate a study of automating Oceanic air traffic handling. The potential for utilization of a computer for Oceanic use which would include conflict prediction should be thoroughly explored."

Observation: A version of the conflict probe in AERA, adapted to the oceanic environment, would meet this need quite well.

Observation: A 160 Klb. flight might initially file for FL330, New York to London. About 2.5 hours later, that flight have burned off about 25 Klbs. of fuel. The pilot would be wise to request a revised clearance to FL370. At 135 Klb., the aircraft will burn 126 lbs. per minute at FL370, while at FL330 it will burn 131 lbs. per minute. The fuel penalty due to a 15 to 20 minute delay amounts to 3/4 gal. per minute, or 12 to 15 gallons.

G.12 Departures Bottleneck at the LaGuardia Departure Position (New York Common IFR Room)

This position handles:

All LGA departures
EWR departures to the northeast and southwest
JFK departures to the west and southwest
HPN (Westchester) departures to the southwest

"The complexity of this operation coupled with the high volume of LGA departures sometimes prevents the LGA departure controller from accomplishing the coordination required to ensure a smooth and unrestricted flow of traffic through his sector. For this reason, there are departure stops, in-trail restrictions, and consequently, delays."

NAPS recommendation: During periods of heavy departure demand, a departure coordinator should be assigned to, among other things, coordinate for higher altitudes, for example:

1. LGA/EWR area departures to the northeast should be cleared relative to actual JFK departures to the northwest.

2. EWR area departures to the southwest should be cleared relative to actual SWEET arrivals from the west.

3. JFK area departures to the east should be cleared relative to actual low altitude enroute traffic via Deer Park.

Observation: The conflict probe feature of AERA has been designed to solve just this kind of problem automatically.

G.13 Departures Bottleneck in the Solberg Sector (New York Center)

"The Solberg route fix (SBJ) is heavily used by aircraft departing all airports in the New York Metropolitan area. This is especially true in the morning hours. The heavy demand and the funnel effect have in the past caused flow restrictions, reroutings, departure stops, and delays." (NAPS Problem 13, p. 153.)

Now: All NY Airports use Solberg as a departure fix to central and southwestern U.S.:

SBJ...J60	to Chicago & Points West
SBJ...J64	
SBJ...J80	to Indianapolis & Points West
SBJ...J48	to Pulaski, VA & Points Southwest
SBJ...J75	to Greensboro, N.C. & New Orleans, Florida
SBJ...MXE	to land Philadelphia or Washington, D.C.

NAPS recommendations:

1. "Establish a new departure route with associated SIDs..." which bypasses SBJ to the north. This route would be used for LaGuardia (LGA) and Westchester (HPN) high performance aircraft requesting FL180 and above via J60."

In keeping with the principle that opposite direction flows be segregated, the committee further recommends that procedures be established to ensure that these westbound departures cross a point well east of SWEET (the fix for LGA arrivals from the west) at or above 15,000 ft. MSL, given that all arrivals to LGA will be cleared to cross SWEET at or below 14,000 ft. MSL.

2. "Continue to institute flow management measures during peak hours to ensure that Solberg departures flow efficiently (e.g., using Holmdel SID, rerouting DCA traffic via Millville-Kenton, etc.)."

G.14 ATC Accommodation of IFR Helicopter Operations

Helicopter operations would much prefer to operate in a manner "...contrary to normal flow of fixed wing air traffic and which further complicates traffic handling in busy areas." Operators stress that their unique operating characteristics and current ATC procedures and criterion are mis-matched. (NAPS Problem 25, p. 215.)

NAPS recommendation: "Accelerated FAA efforts to establish helicopter procedures and separation criteria."

APPENDIX H

Maximum Lateral Error in a Straight Line Stereographic Approximation of a Great Circle Route

This derivation is based on that provided by B. G. Sokkappa in Reference 11. The problem to be solved is set up in Figures H-1 and H-2.

Given:

2R = mean diameter of the earth, 6876 n. miles.

s = distance between the great-circle endpoints, A and B, in n. miles.

ϕ = s/R radians

d = distance between the tangency point, T, and the midpoint of the great-circle route, C, in n. miles.

θ = d/R radians

Find:

e = distance between the midpoint, C', of the great-circle route between A and B projected into the stero-plane and the midpoint, D', of the straight line route drawn in the stereo-plane between the projections of endpoints A and B.

Argument:

$e = C'D' = D'G$ (isoseles triangle)

$D'G \approx CE$ (R>>CE and d)

$\frac{CE}{MF} = \frac{PC}{PF}$ (parallel lines crossing lines enamating from a common point)

$$CE = MF \left[\frac{PC}{PF}\right]$$

where:

$MF = MC \tan \theta/2$
$MC = R - R \cos \phi/2$

APPENDIX H

(Cont'd)

and

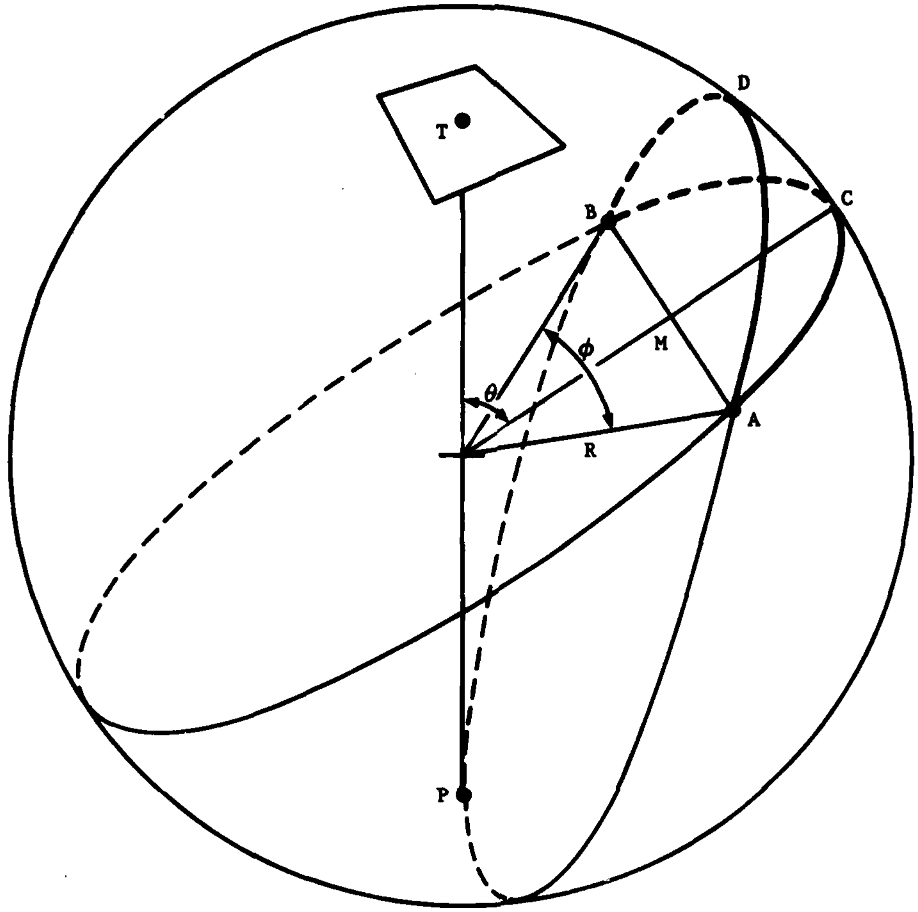
$$PC = 2R \cos \theta/2$$
$$PF = PC - CF = PC - \frac{MC}{\cos \theta/2}$$

so

$$e = R(1 - \cos \phi/2) \tan \theta/2 \left[\frac{2R \cos \theta/2}{2R \cos \theta/2 - \frac{R(1 - \cos \phi/2)}{\cos \theta/2}} \right]$$

$$e = (1 - \cos \phi/2) \tan \theta/2 \left[\frac{(2R) \cos^2 \theta/2}{2 \cos^2 \theta/2 - 1 + \cos \phi/2} \right]$$

End of argument. Representative values are tabulated in Table A-8.



T = Tangency point for stereographic plane

P = Projection point diametrically opposite T

R = Earth's radius (3438 n. miles)

A,B = Endpoints defining a great circle route

C = Midpoint of the great circle route

PAB = Plane of projections for a straight line drawn between the projections of A and B in the stereographic plane.

ϕ = Angle subtended by the great circle route

θ = Angle subtended by the displacement of the great circle route at C from T.

FIGURE H-1
STEREOGRAPHIC PROJECTION OF A GREAT CIRCLE ROUTE

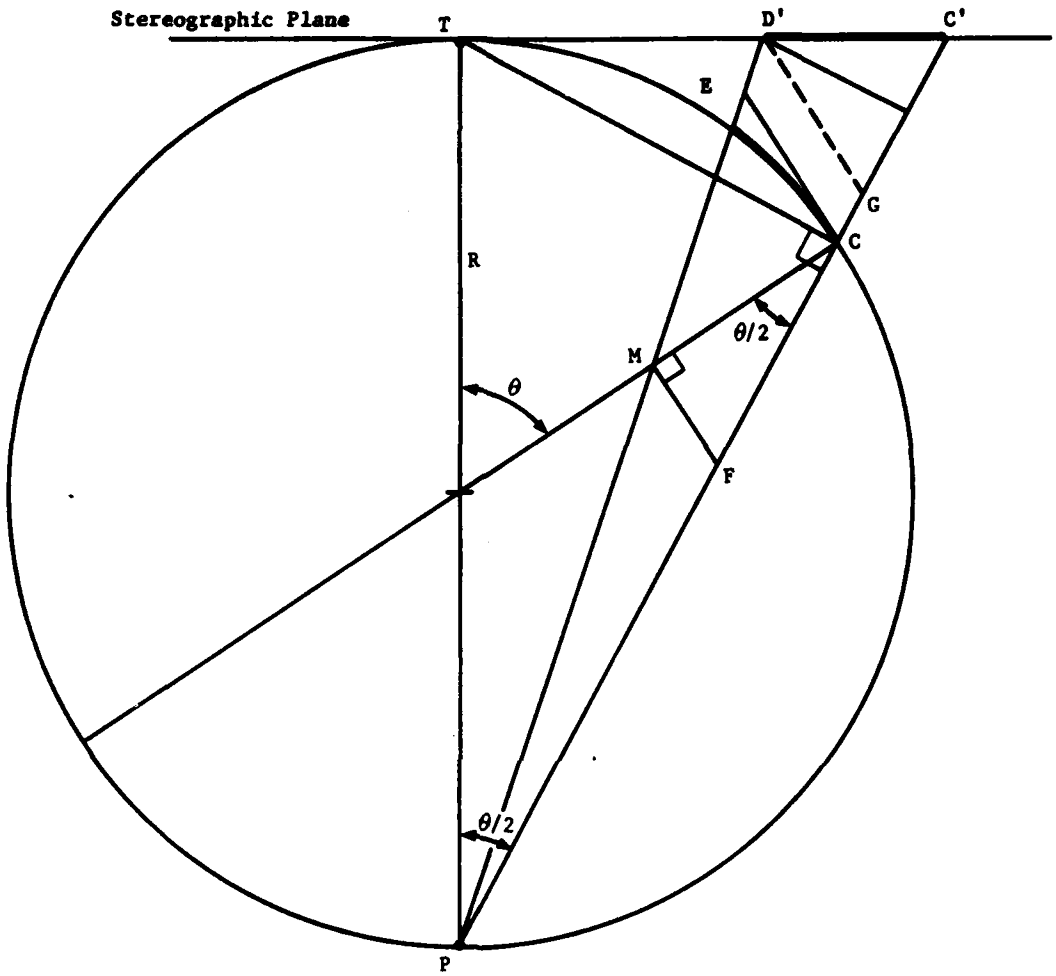


FIGURE H-2
CROSS-SECTION OF THE STEREOGRAPHIC PROJECTION AT THE GREAT CIRCLE ROUTE'S MIDPOINT

APPENDIX I

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